OCS Study
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90-0063

Ecological Research Associates

MONITORING BEAUTORT SEA WATERFOWL AND MARINE BIRDS

Revised Draft Report

from

LGL Alaska Research Associates inc.
505 West Northern Lights Boulevard., Suite. 201
Anchorage, Alaska 99503

for

U.S. Minerals Management %-vice
Alaska Outer Continental Shelf Region
U.S. Department of Interior
Room 110, 949 East 36th Avenue
Anchorage, Alaska 99508

Contract no. 14-35-0001-30491
LGL Rep. No. TA 863-1

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by

Stephen R. Johnson

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The opinions, findings, conclusions, or recommendations expressed in this report are those of the author and do not necessarily reflect the views of the U.S. Dept. of the Interior, nor does mention of trade names or commercial products constitute endorsement or recommendation for use by the Federal Government.

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ABSTRACT

The purpose of this project was to design and implement a monitoring protocol for marine waterbirds inthe Jones-Return islands area of the central Alaska Beaufort Sea. Because of its overwhelming and widespread abundance, relatively sedentary behavior, ease in counting, and the extensive historical database, the oldsquaw duck (*Clangula hyemalis*) was selected as the focal species for this study. Two null hypotheses were formulated concerning potential changes in the numbers and distribution of oldsquaws in relation to OCS development in the industrial area, compared to a control area (Stockton-Maguire-Flaxman islands area) located about 50 km to the east.

A 9-year historical database (1977 through 1984, and 1989) was analysed using multivariate techniques to determine which of several predictor variables recorded during past aerial surveys significantly influenced oldsquaw density in the central Alaska Beaufort Sea. Separate analyses were conducted for the complete open-water period (5 June to 23 September), and for the molt period of oldsquaws (15 July to 15 August), when they are flightless and relatively sedentary in the study areas. The results of the two multiple regression analyses indicated that only about 57% and 68%, respectively, of the total amount of variation in oldquaw density during the two periods could be explained by predictor variables recorded during aerial surveys. Candidate predictor variables were: year of study, day of year, time of day, wind speed and direction, habitat, east-west position (study area) of the transect, distance of the transect from a barrier island, water depth beneath the transect, wave height and amount of ice recorded on the transect. Predictor variables associated with habitat, day of the year, time of day of the survey, amount of ice, and wave height recorded on transect during the survey had the most significant effect on oldsquaw density. Measurement error and influences outside the study area no doubt also had a strong influence on the results of the regression analyses.

Based on the regression analyses, an intensive program of aerial surveys and an 'analysis of covariance' statistical procedure was designed to detect differences in oldsquaw density that may be associated with OCS activity in the industrial area in future years. An alternative 'repeated measures analysis' was also considered as a possible more powerful (but very much more complicated) statistical procedure for testing the null hypotheses.

The Control area is situated along a part of the Beaufort Sea coast where very little coastal or nearshore industrial activity has occurred. Although several oil wells have been drilled during winter on or adjacent to a few of the islands in the Control Area (e.g., Challenge Island), and on the adjacent mainland tundra (e.g., Pt. Thompson), the area is relatively pristine and undisturbed compared to the Industrial study area.

An Assessment of Variables Affecting Oldsquaw Densities

Several important and relatively well understood variables may influence the number of oldsquaws present in the two study areas. Based on the results of earlier studies, we have selected relevant predictor variables for use in a multiple regression analysis, which allows us to quantitatively determine which variables are most important in controlling the dependent variable, i.e., the densities of oldsquaws recorded on aerial survey transects.

Each of the relevant predictor variables (independent variables) selected for use in the multiple regression analysis of oldsquaw density (dependent variable = DENSTRAN) on transects in the study areas is discussed below, and a brief rationale is given for their inclusion in the analysis.

1. Year of study. Earlier studies (Johnson and Richardson 1981) and subsequent analyses in the present study (Appendix 1) have shown that densities of oldsquaws on specific transects in the Jones-Return islands area varied considerably from one year to the next. Consequently we have included a YEAR term in the analysis.

2. Time of the year (day of the season) that sampling occurred. Previous studies clearly showed that use of nearshore habitats by oldsquaws and other marine birds was highest during the summer open water period (Johnson and Richardson 1981). Numbers and densities were consistently high during the month-long period from mid-July to mid-August when male oldsquaws congregated in nearshore lagoons to molt (Fig. 5 in Johnson 1985; Garner and Reynolds 1986:129). Consequently we have included a DAY term in the analyses.

avian biomass in the nearshore Beaufort environment, and during July and August, when they molt their feathers, they are flightless and particularly vulnerable to water-borne contaminants and disturbances. Most other species occur in relatively small numbers or are transients in the study area, so none of these species were thought to be suitable candidates for a monitoring program.

There currently is a 9-year base of information on the distribution and abundance of marine birds in the central Alaska Beaufort Sea. During all years for which sufficient data are available, oldsquaws represent about 93% of all birds seen during aerial sampling from early June through late September, In this report we outline our approach to developing and implementing a monitoring protocol that is based on a series of low-level aerial surveys of oldsquaws. It accounts for the fact that there are several complex and interactive natural variables (i.e., migration schedules of birds, time of year, time of day, wind speed and direction, presence or absence of a barrier island nearby, distribution of ice, etc.) that may significantly influence the behavior of these birds, and therefore significantly influence the results of aerial surveys of them in the nearshore Beaufort Sea area.

The Jones-Return Islands Industrial Area

The terms-of-reference identified the Jones-Return island chain, west of Prudhoe Bay, Alaska, as the Industrial study area for this monitoring program. These islands have remained relatively undeveloped over the past two decades during the course of oil and gas exploration on the adjacent mainland tundra, although there has been significant industrial activity in nearshore waters in the general area.

The Stockton-Maguire-Flaxman Islands Control Area

The Stockton-Maguire-Flaxman islands area, located about 50 km east of the Industrial area, was selected as the Control area for the present monitoring study. The area is similar in structure and size to the Industrial Area, it is used extensively by oldsquaws and other waterbirds, and there is a base of historical aerial survey data for use in statistical analyses and comparisons.

EXECUTIVE SUMMARY

The purpose of this project is to design and implement a monitoring protocol in nearshore waters of the Alaska Beaufort Sea for marine waterbirds, principally marine waterfowl, which are abundant in this area (Johnson and Richardson 1981, Johnson and Herter 1989). The need for such a protocol is most urgent in the central Beaufort Sea area (e.g., Jones-Return islands area), where nearshore exploration and coastal development have occurred over the past decade, and are likely to escalate in the future.

In late September 1983, a MMS/NOAA-sponsored workshop was held in Girdwood, Alaska, to develop a monitoring strategy for the Alaska Beaufort Sea (Dames and Moore 1984). The concept of monitoring Beaufort waterbirds is based on the following conclusions of the 1983 workshop:

> Marine birds are abundant and are a biologically and socially important component of the nearshore Beaufort Sea ecosystem.
>
> Some species of Beaufort Sea marine birds, especially marine waterfowl such as the oldsquaw duck (*Clangula hyemalis),* are ubiquitous, relatively easy to detect and count, and have been well studied prior to industrial development; therefore they are appropriate candidates for monitoring.
>
> A monitoring protocol should be designed to insure that industry-related influences on marine birds are discernible from other natural influences, i.e., should involve a rigorous design and statistical approach that includes both experimental and control areas and draws on all relevant historical information collected in the study area.

The 1983 workshop identified several potential waterbird species for monitoring. The oldsquaw duck was selected over other species because it is the most abundant and widespread local waterbird in the nearshore Beaufort Sea, the zone where virtually all exploration and development have occurred in the Beaufort marine system. Data presented at the workshop confirmed that during the summer open-water period oldsquaws represent most of the

3. Time of day that sampling occurred. Long-term, continuous observations in the Jones-Return island area clearly showed that in undisturbed situations molting oldsquaws exhibited a 24-hr cycle of distribution, abundance and behavior in barrier island-lagoon habitats (Johnson 1982a, 1983, 1985). We have included a TIME term in the analysis.

4. Water depth in the sampling area. Studies of feeding behavior of oldsquaws in the Jones-Return islands area indicated that they fed preferentially in the shallow nearshore lagoons in the area. These studies also showed that the invertebrate prey of oldsquaws was most abundant in the deeper parts (2-3 m) of the lagoons, and that oldsquaws fed more efficiently (had more food in their stomachs) in areas of the lagoon where invertebrates were abundant (Johnson 1984a, Johnson and Richardson 1981). A water DEPTH term was included in the multivariate analysis.

5. Location of the sampling area along an east-west axis. Although oldsquaws congregate in barrier island-lagoon habitats along the entire Beaufort Sea coast where suitable habitat exists, earlier studies showed that densities of oldsquaws were consistently higher in some parts of the study area compared to others (Johnson and Richardson 1981, Johnson 1984b, Garner and Reynolds 1988). As a consequence, we have included an interval scale WESTEAST term in our analyses.

6. Proximity of sampling area (transect) to a barrier island. Earlier studies, and preliminary analysis of data in the present study, indicated that the numbers and densities of oldsquaws and other waterbirds on transects close to barrier islands, compared to offshore transects or those closer to the mainland, most closely reflected the overall density of oldsquaw in the general area. Two predictor variables included in our analyses relate to proximity of the sampling area to a barrier island. One measure (DIST) is the absolute value (on a continuous scale) of the average distance of the transect from the nearest barrier island.

The other measure (HABITAT) was a categorical variable expressed by a set of four dummy variables (see Wilkinson 1987, Draper and Smith 1981), and analysis results were combined into a single F-ratio (with 4 d.f. rather than the usual 1 d. f.) reflecting the overall effect of habitat on oldsquaw density.

7. Wind speed and direction in the sampling area during the sampling period. Prevailing winds in the central Beaufort Sea area during the summer are northeasterly or northerly (Brewer et al. 1977), and various studies have indicated that the density of oldsquaws on different transects in the Jones-Return island area was significantly related to the speed and direction of wind during aerial and ground-based sampling. Wind speed (WSPD) was measured in km /hr, and wind direction was measured on several scales--a 360° scale (WDIR) and on an ordinal octant scale (ORDWND). Two other continuous measures of wind speed and direction were included as predictor variables, the northern (NCOMWND) and northeastern (NECOMWND) components of wind.

8. Percent ice-cover on-transect in the study area during the sampling period. Earlier studies indicated that densities of oldsquaws during the male molt period in the Jones-Return islands area were higher in lagoon habitats where there was consistently less ice on-transect than in areas seaward of the barrier islands (Johnson and Richardson 1981). Consequently, we included the measure of estimated percent ice on-transect (ICE) as a predictor variable in the multiple regression analysis.

9. Wave height on-transect in the study area during the sampling period. Wave height on transects in the sampling area is directly related to the direction and speed of wind, which were discussed previously as separate predictor variables. But wave height also has a significant influence on the detectability of oldsquaws and other marine birds swimming on the water, and thus affects the apparent density of oldsquaws recorded on-transect. Wave height is a standard measurement recorded during the course of LGL aerial surveys, and consequently has been included as a separate predictor variable (WAVEHT) in our analyses.

10. Study Area. There are two distinct sampling areas or categories in this study (Industrial and Control areas). As a result, analyses were based on a single dummy variable (Wilkinson 1987, Draper and Smith 1981) reflecting

the overall effect of the particular study area within which the transect is located.

Results of Multiple Regression Analyses

Two separate multiple regression analyses were conducted, one for the complete study period using all available data for all transects surveyed on any date (5 June to 23 September) during all years of study. Only complete sets of data, i.e., no missing variables, were used for this analysis. Another similar analysis was conducted using data only from the oldsquaw molt period (15 July to 15 August = days 46 to 76) during all years of study.

The multiple regression analysis for all dates and years (complete study period) showed a strong relationship between the predictor variables and the density of oldsquaws (n = ***474,*** multiple R = 0.76, Appendix 2); several of the predictor variables were nominally significant as predictors of the dependent variable DENSTRAN. Nevertheless, only about half (multiple R^2 = 0.57) of the variation in oldsquaw density for the open water period was accounted for by the predictor variables used in the present multiple regression analysis.

Results of the multiple regression analysis of data from the oldsquaw molt period (15 July-15 August) were very similar to those from the overall study period. There was a strong relationship between several of the predictor variables and the density of oldsquaws (n = 275, multiple R = 0.83, Appendix 3). About two-thirds (multiple R^2 = 0.68) of the total variation in oldsquaw density was accounted for by the variables and interaction terms used in the present multiple regression analysis.

Wave height, habitat type, day of year and day of year x habitat interaction, time of day x habitat interactions, and ice cover x habitat interactions all were important (and statistically significant) variables that helped predict oldsquaw density in the study areas. Analysis of residuals helped determine whether variables conformed to necessary assumptions of multiple regression analysis (normally distributed residuals, appropriate transformation of data, homogeneity of variance, linearity of relationships, etc.).

Influences That May Effect Oldsquaw Density

The overall proportion of variation explained by the predictor variables in the two multiple regression analyses was only about 0.56 for the complete study period, and 0.67 for the molt period. These values are less than hoped for and indicate the effects of measurement error and unmeasured variables (inside and outside the study area) that may influence oldsquaw distribution, abundance and density.

Measurement error is a notable factor in many of the variables presented in this study, especially environmental factors such as amount of ice, wave height, wind direction and speed, etc. estimated on-transect during the course of aerial surveys. This type of error is somewhat reduced when experienced observers conduct aerial surveys, but some measurement error is inherent in any sampling program, especially one conducted from a fast-moving and low-level aircraft.

A major shortcoming of earlier studies has been that there was no provision for recording the level of human activity on transects, aside from the obvious presence or absence of a major structure, such as an artificial island, causeway, or drilling structure.

Another major confounding factor is the degree to which the distribution and abundance of oldsquaws may be determined by influences outside the study area, and therefore are not measurable in a local or regional monitoring program. This potential source of error may have a significant influence on the distribution, estimated abundance, and density of oldsquaws in both study areas. We suspect that factors not included in the regression analyses, such as the ones described here, may have had a significant influence on the numbers and densities of oldsquaws recorded during past years in central Beaufort barrier island-lagoon systems. Although some of these influences are difficult (if not impossible) to measure, it is possible to design a monitoring program so that much of the remaining variability could be accounted for. The implementation of such a program is described below.

Implementation of a Monitoring Protocol

Design Considerations

Results from earlier studies (Johnson and Richardson 1981, Troy et al. 1983), and from the multivariate analyses presented above have indicated that some of the variation in apparent oldsquaw density is attributable to sighting conditions, as influenced by wind, sea state, ice cover, sun glare, etc. Additional variation may be attributable to local variations in human activities within the areas designated as either Industrial or Control. It is important to account for the causes of as much of this variation as possible in order to maximize the power of the statistical procedures used to identify the presence and magnitude of any industrial effects, either broad-scale (i.e., Industrial Area vs. Control Area) or fine-scale (transect-to-transect within one or both study areas). Consequently, in future analyses associated with the Beaufort Waterbird Monitoring Protocol, an additional independent variable, one that has been absent from all earlier analyses, needs to be included. This variable is “Levels and types of industrial activities in the study areas during the sampling periods. ”

It is also possible that additional meteorological and oceanographic factors influence the distribution, abundance, and movements of oldsquaw ducks. We recommend that factors such as seasonal upwelling potential and/or seasonal mean wind speed and direction (Craig et al. 1984; LGL et al. 1990), which are known to influence the distribution, abundance and movements of anadromous fish in the nearshore Beaufort, should also be considered in the interpretation of oldsquaw data in future analyses.

Sampling Procedures

The need for powerful analytical approaches in the monitoring program will necessitate the use of field sampling procedures that satisfy the requirements of those analysis methods. We have organized the future sampling in such a way to obtain data for the following spatial and temporal categories:

islands or in offshore areas. Also, changes in density along the mainland shore may be important in understanding simultaneous changes in numbers in other habitats.

Schedule of Surveys

Based on the results of earlier studies and on the results of the regression analyses described above, the appropriate period for surveys of marine birds in both Beaufort study areas (Industrial and Control) is from mid-July until late August or early September, i.e., during the oldsquaw molt period. We recommend that four separate surveys be conducted during this period at about 8-10 day intervals, starting on about 15 July. All transects should be surveyed three times during each of the four 5-day survey periods. This will provide the three replicate surveys during each sampling period that are essential for variance computations.

We also recommend that surveys not be conducted during periods of high winds (>10 kts.) and heavy ice. Since we have recommended that monitoring surveys start on 15 July, after ice break-up has occurred in the marine system, influences of heavy ice-cover should be less of a problem in the future than during some previous years when some surveys began as early as 5 June. Beaufort Sea lagoons are usually ice-free by mid-June.

Data Recording

Recording of aerial survey data has been standardized according to procedures established during a set of structured surveys conducted in early August 1989. During those surveys we adopted 30-second time-period intervals for recording the number of birds on and off transect and for recording an array of information about the survey conditions and prevailing environmental conditions. Factors such as amount of ice on and off transect, wave height, glare on the water surface, wind speed and direction, proximity to barrier island or other structure, apparent type and level of human activity on and off transect during the time period, and any changes in any particular variable noted during the course of the survey.

Information is to be collected for all species of birds and mammals observed on and off the transects. Tape recorders are used to record the information, and the data are later transcribed and coded onto standard forms that provide for all of the information described above. Linear and areal densities are computed for all species sighted on-transect during all surveys; linear densities are also computed for on+off-transect sightings. These data are verified, validated and tabulated by species, year, date, time-period, transect, and observer.

Analysis Procedures

The multiple regression approach described in the preceding sections is optimum for examining historical data collected in a rather unstructured manner. However, greater statistical power and precision can be obtained by collecting future data in the more structured fashion summarized above. These data should be examined primarily by analysis of variance (ANOVA) and analysis of covariance (ANCOVA) methods.

In the present study, many factors must be taken into account in the analysis. These will include variations in waterbird density attributable to sampling period, time of day, water depth, proximity to barrier island, east-west position within the study area, wind and ice conditions during surveys, local variations in human activity, etc. Because the survey design will be precisely structured with regard to year, study area, sampling period, habitat, and transect, these can be identified as factors in an analysis of variance. Wind direction and speed, ice cover, wave height and other unpredictable continuously-distributed variables will be best handled as covariates rather than as categorical factors. Measurements of human activity along each transect will be another covariate; by considering this variable, we can assess the possibility of small-scale industrial effects on waterbird density.

Analysis of Variance and Covariance

In order to test whether there have been changes in densities of molting male oldsquaws in selected Beaufort Sea index area that may be attributable to industrial activies, we recommend a 5 factor–5 covariate analysis of covariance statistical approach. The five factors are year, area, sampling period, habitat and transect, and the five covariates are ice cover, wind direction, wind speed, wave height, and the measure of human activity (disturbance) on each transect. The replicates are the three separate days of surveys within each sampling period.

It is possible that replicate surveys flown within a 5-day sampling period will not be independent of each other, i.e., the density of oldsquaws seen on transects during one survey may be related to those recorded on the same transect during an earlier survey. Presently the amount of movement within a transect or from one transect or habitat to another by oldsquaws is unknown, thus the actual amount of interdependency of oldsquaw densities on transects or habitats among surveys is unknown. One study (Brackney et al. 1985) did show, however, that oldsquaws molting in barrier island-lagoon habitats in the Arctic National Wildlife Refuge (ANWR) moved as much as several km per day, with an average of about 0.7 km per day. Such movements indicate that oldsquaws may not remain in the same small area for prolonged periods of time. Nevertheless, the extent to which birds move from one area to the next along adjacent sections of the Beaufort Sea coast is completely unknown. Consequently, the degree to which replicate surveys randomly sample populations of oldsquaws is also currently unknown.

The ANCOVA Model

The ANCOVA model most appropriate and best suited to test for significant differences in oldsquaw densities over space and time in the monitoring protocol is given in the following equation:

$$\text{Mean} + A + Y + YA + H(A) + YH(A) + P(Y) + AP(Y) + T(H(A)) + YT(H(A)) + \text{error}$$

Parentheses indicate that some factors are nested within others, e.g., H(A) is interpreted as habitat nested within area. The ANCOVA can be visualized as an ANOVA with the addition of covariates to help standardize the basic unit of analysis (oldsquaw density on a transect in a habitat in a study area during a survey in a sampling period within a year). The ANOVA model is nested (sampling period within year, habitat within study area, transect within habitat) and factor effects are mixed, i.e., some are fixed and some are random. Year, area and period are fixed and interpretations of analysis results of these factors can only be extended to the levels tested. On the other hand, habitat and transect are considered random effects since they could have been defined in a variety of different ways to represent the spatial structure of the factor.

The statistical significance of the year x area interaction, after allowance for other factors in the analysis, will be the main test of the possibility of a large-scale industrial effect on oldsquaw density. This is one of the most important statistical tests in the monitoring protocol, and is directly relevant to the null hypotheses around which this study is structured.

Simple graphical presentations of the relationships among variables can be used to help explain the statistical results and make them clear to readers who are not especially knowledgeable about the ANCOVA statistical procedures. These graphical approaches would be especially useful in examining the effects of covariate interactions (i. e., non-homogeneous slopes).

The appropriate analysis of covariance (ANCOVA) procedures, suggested by Bliss (1970) and Huitema (1980), are as follows:

1. Log-transform the density data in order to reduce the skewness inherent in such data.
2. Conduct the ANCOVA with the 5 covariates and their 10 interaction terms with year and area. Interactions with the finer scale temporal and spatial terms have been ignored since they are nested within year and area.
3. If any of the interaction terms involving covariates are not significant, then those covariate terms should be removed from the model. However, they should be removed sequentially in such a way that the term with the greatest P-value (least significant) is removed first; the ANCOVA model is then rerun and the remaining interaction terms are examined. This process is repeated until all non-significant interaction terms have been removed.
4. Conduct the ANCOVA using the factors, covariates and interaction terms remaining after following the procedures outlined in 3.) above. Also conduct an ANOVA (no covariates), and an ANCOVA with only the human activity covariate so the overall effect of human activity (industrial disturbance) and the "environmental" covariates (wind, waves, ice) can be isolated.

The proposed three surveys of each transect during each sampling period in the field season will provide the replication necessary for the ANCOVA. The ANCOVA will identify how much of the variation in densities of oldsquaws is attributable to each factor, i.e., year, study area, sampling period, habitat and transect; and to each covariate, i.e., wind speed, wind direction, wave height, ice cover and local human activity (disturbance).

As an alternative, we have also recommended that a Repeated Measures (RM) statistical analysis also be conducted after the first field season in order to compare this procedure to ANOVA analysis procedures, which may violate basic ANOVA assumptions. RM procedures are very complex when more than one covariate is involved, so this statistical approach will be used only if it is found that replicate sampling of aerial survey transects is found not to be independent from one survey to the next--a violation of basic ANOVA assumptions.

We are confident that the monitoring plan presented above is the most appropriate and statistically powerful approach. Nevertheless, after one complete season of data collection and subsequent analyses, it may be necessary to modify some aspects of the field procedures or some of the analyses. Such modifications will be documented and a complete and thorough rationale for their inclusion in the protocol would be provided.

ACKNOWLEDGEMENTS

This study was funded by the U.S. Department of Interior, Minerals Management Service (MMS), Anchorage, Alaska. We especially thank Steve Treaty, Cleve Cowles, and Jerry Imm of MMS for their guidance and patience during this study.

Most of our earlier studies of marine waterbirds in the central Alaska Beaufort Sea were funded and supported by the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of Interior's Bureau of Land Managment (BLM) and MMS, through the Outer Continental Shelf Environmental Assessment Program (OCSEAP). Other studies were supported by Shell Oil Company, and ARCO Alaska Inc. for the U.S. Army Corps of Engineers.

Rolph Davis, Alan Birdsall, Joe Truett, Benny Gallaway, Tom Wetmore, John Richardson, Scott Anderson, Bill Gazey, Josh Baker, Declan Troy, Lynn Maritzen, Brian Harvey, and many others at LGL provided management and/ or technical assistance during some of our government and industry sponsored studies of marine birds in the Beaufort Sea.

Many people worked in the field during 1977-1984 on the various studies of marine birds that are the basis of this report; we especially thank Chip Welling, Gary Searing, John Richardson, Joe Truett, Doug Schamel, Dale Herter, Phil Martin, Bob Burgess, Declan Troy, Dave Rudholm, and Craig Hohenberger. Jim Helmericks and his family provided aircraft support and room and board during many of our studies along the Beaufort Sea coast.

Joe Truett, Randall Howard and Bob Pollard were instrumental in recovering some of the historical aerial survey data. I especially thank Gary

Searing for working tirelessly to help reformat, organize, and clean-up the historical aerial survey data.

John Richardson (LGL Limited) contributed significantly to the experimental design for this study and suggested improvements to this report; he and Bill Gazey (W.J. Gazey Research) advised on statistical matters. Rolph Davis also helped design this study, and has guided the management of the project. William Griffiths helped obtain missing weather data for some survey periods and shared his ideas and experience regarding weather and oceanographic influences in the study area. Nell Stallard made editorial comments and helped produce this report.

INTRODUCTION

Purpose

The Outer Continental Shelf Lands Act (OCSLA) and its amendments include provisions (1) for post-lease monitoring studies to provide information that can be compared with any previously collected information in order to identify significant changes in quality and productivity of leased environments, (2) for establishing trends in the areas studied and monitored, and (3) for designing experiments to identify the causes of such changes. The "Notice of Sale for Beaufort Lease Sale 97", which includes the Jones-Return islands, contained stipulations for the protection of biological resources in the lease sale area.

The purpose of this project is to design and implement a monitoring protocol in nearshore waters of the Alaska Beaufort Sea for marine waterbirds, principally marine waterfowl, which are abundant in the area (Johnson and Richardson 1981, Johnson and Herter 1989). The need for such a protocol is most urgent in the central Beaufort Sea area (e.g., Jones-Return islands area, Fig. 1), where nearshore exploration and coastal development have occurred over the past decade, and are likely to escalate in the future.

Background

In late September 1983, an MMS/NOAA-sponsored workshop was held in Girdwood, Alaska, to develop a monitoring strategy for the Alaskan Beaufort Sea (Dames and Moore 1984). The concept of monitoring Beaufort waterbirds is based on the following conclusions of the 1983 workshop:

Marine birds are abundant and are a biologically and socially important component of the nearshore Beaufort Sea ecosystem.

Some species of Beaufort Sea marine birds, especially marine waterfowl such as the oldsquaw duck (*Clangula hyemalis)*, are ubiquitous, relatively easy to detect and count, and have been well studied prior to industrial development; therefore they are appropriate candidates for monitoring.

A monitoring protocol should be designed to insure that industry-related influences on marine birds are discernible from other natural influences, i.e., should involve a rigorous design and statistical approach that includes both experimental and control areas and draws on all relevant historical information collected in the study area.

The 1983 workshop identified several potential waterbird species for monitoring. The oldsquaw duck was selected over other species because it is the most abundant and widespread local waterbird in the nearshore Beaufort Sea, the zone where virtually all exploration and development have occurred in the Beaufort marine system. Data presented at the workshop confirmed that during the summer open-water period oldsquaws represent most of the avian biomass in the nearshore Beaufort environment, and during July and August, when they molt their feathers, they are flightless and particularly vulnerable to water-borne contaminants and disturbances. Most other species occur in relatively small numbers or they are transients in the study area, so

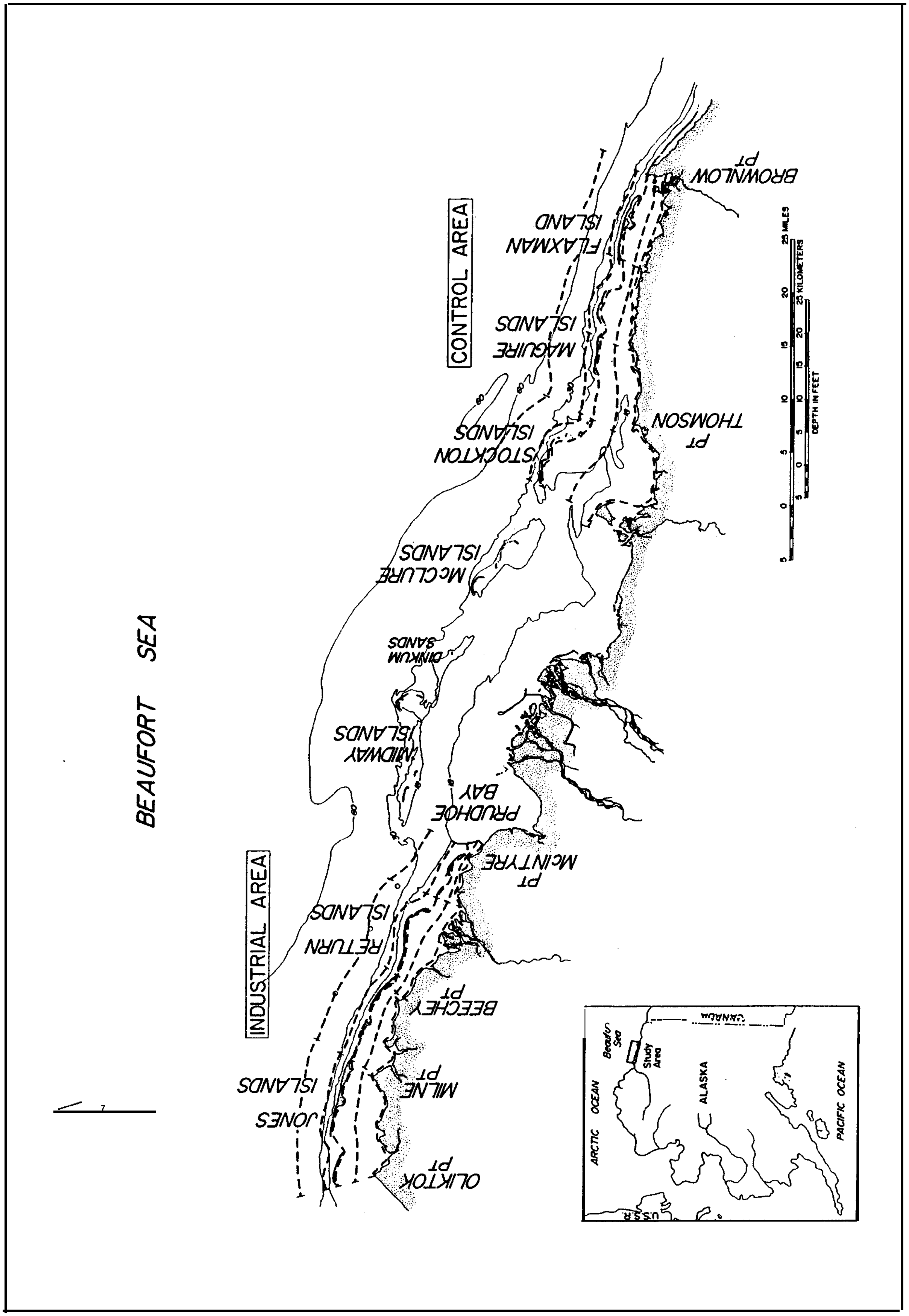

Figure 1. Central Alaska Beaufort Sea with Industrial and Control study areas.

none of these species were thought to be suitable candidates for a monitoring program.

In this report we outline our approach to developing and implementing a monitoring protocol that is based on a series of low-level aerial surveys of marine waterfowl, primarily oldsquaws. It accounts for the fact that there are several complex and interactive natural variables (i.e., migration schedules of birds, time of year, time of day, wind speed and direction, presence or absence of a barrier island nearby, distribution of ice, etc.) that may significantly influence the behavior of these birds, and therefore significantly influence the results of aerial surveys of them in the nearshore Beaufort Sea area (Johnson 1982a, 1983, 1985; Johnson and Richardson 1981; Dames and Moore 1984).

Thus, a monitoring program that is designed to detect the influences of industry activities on nearby birds must test specific hypotheses that relate to (1) the birds chosen to be monitored, and (2) the types of industry activities in the study area. The following null hypotheses have been constructed with such factors in mind:

> HOI: There will be no detectable change in relative densities of molting male Oldsquaws in selected Beaufort Sea index areas.

> H_o2: Changes in male oldsquaw distribution patterns are not related to OCS oil and gas development activity.

These two hypotheses, as presented by LGL at the Beaufort Sea monitoring workshop (Dames and Moore 1984), were constructed after six years of aerial surveys and supplemental research on the distribution, abundance and behavior of marine waterfowl, mainly oldsquaws, in the Jones-Return islands area of the Alaska Beaufort Sea. During this period, aerial survey procedures were modified to improve the distribution and resolution of sampling, and the surveys were continued through 1984, thus establishing an 8-year base of information on the distribution and abundance of oldsquaws (primarily molting males) in and adjacent to the Jones-Return islands area. Similarly, when the present study was initiated in August 1989, a series of test surveys (three surveys of all transects during a 5-day period) in the Jones-Return islands and the Stockton-Maguire islands area were conducted. As a result, there currently is a 9-year base of information on the distribution and abundance of marine birds (during the oldsquaw molt period) in the central Alaska Beaufort Sea.

MONITORING DESIGN AND RATIONALE

Review of Existing Information

As mentioned above, most of the research on marine birds in the central Alaska Beaufort Sea nearshore zone has been conducted by LGL scientists. Ecosystem process studies in Simpson Lagoon for NOAA/OCSEAP were conducted from 1977 to 1980 and again in 1984, and studies associated with the Waterflood Environmental Monitoring Project for the U.S. Army Corps of Engineers were conducted in 1981 through 1983.

All of these investigations included aerial surveys of the distribution and abundance of marine birds in nearshore waters in the Jones-Return islands area, and to a lesser extent in adjacent nearshore areas (Johnson and Richardson 1981; Johnson 1985; Troy et al. 1983; Troy 1984). We also investigated the daily cycle of behavior of oldsquaws by making continuous observations of their distribution, abundance, and behavior during the peak of the male molt period near barrier islands in the Jones-Return islands group (Johnson 1982a, 1983). The data from these surveys are archived at LGL Limited, Sidney, British Columbia, Canada.

Other aspects of these larger investigations included studies of (1) the effects of human disturbance on the distribution and behavior of oldsquaws in barrier island-lagoon habitats (Johnson 1982a, 1983), and (2) studies of the distribution and abundance of the invertebrate prey of oldsquaws (Johnson 1984a; Johnson and Richardson 1981).

The relevant results of all of these studies are discussed below in the context of the design and rationale for the Beaufort waterbird monitoring protocol.

The Oldsquaw as the Focal Species

As we recommended at the MMS/NOAA-sponsored Beaufort Monitoring Workshop in 1983 (Dames and Moore 1984), the oldsquaw duck is the appropriate focal waterbird species for the monitoring protocol. No other species of waterbird is present in sufficient numbers in the study area for a period of time long enough to be considered a suitable candidate for monitoring. Nevertheless, we have reviewed and compared the suitabilities of other possible candidate species for the monitoring program.

Several hundred Pacific eiders (*Somateria mollissima v-nigra*), Arctic terns (*Sterna paradisaea*), glaucous gulls (*Larus hyperboreus*), and brant (*Branta bernicla*) nest and rear their young on barrier islands in the central Alaska Beaufort Sea, but their numbers are too few (eiders, terns, gulls, brant), their distributions too clumped (eiders, gulls, terns, brant) and their habits too secretive (eiders, brant, terns) for them to be considered suitable candidates for monitoring without intensive ground-based monitoring.

Thousands of juvenile phalaropes and hundreds of Arctic terns and glaucous gulls move to barrier island habitats to feed starting in early August, prior to their southward fall migration (Johnson and Richardson 1981). But the year-to-year variations in the numbers of these species encountered in Beaufort Sea habitats are great (Johnson and Richardson 1981, Johnson 1984c). In years with high reproductive success at tundra nesting locations, there are many juvenile phalaropes, gulls and terns along the barrier islands in August and early September; in years of bad production, there may be few. This is also true for eiders and brant.

Consequently, although these species are often detected and recorded during ground and air based investigations, their numbers can be highly variable, reflecting aspects of their life history not associated with activities in coastal barrier island-lagoon and nearshore habitats.

On the other hand, tens of thousands to hundreds of thousands of molting male oldsquaws use lagoon and nearshore habitats along the Beaufort Sea coast during mid-July through late August or early September, regardless of high or low production of young in tundra habitats. They congregate at locations where there is protection from wind, waves and moving ice and where there is abundant food to support them while they replace virtually their entire plumage. During this molt period oldsquaws are flightless for nearly a month (Johnson 1982a,b; 1983; 1984a,b; 1985). Thus, oldsquaws are relatively sedentary during the July-August peak of the molt period, and are relatively easy to count at this time. OCS-related activities in nearshore environments are more likely to affect, in a consistent and measurable manner, the local and general distribution and abundance of oldsquaws than of the other species mentioned above.

In a monitoring program such as the one being designed here, it is essential to focus on the species that offer the best chance of detecting changes related to development in the area of interest. Such species should be present in the areas of concern for a reasonable period of time, should be abundant and widespread, and should be relatively easy to count reliably.

Furthermore, the biology of the focal species should be well enough understood to separate natural variability in its numbers and distribution from man-caused variability. There are few species in the nearshore Beaufort Sea that fit these criteria. The prime candidates are (1) oldsquaws in most nearshore habitats during July and August, (2) the phalaropes along barrier island beaches during a 10 to 20 day period in August, and (3) glaucous gulls primarily along barrier island beaches during mid-August (Johnson and Richardson 1981). Only the oldsquaw is present in sufficient numbers in most nearshore habitats throughout the study area for a period long enough to be sufficient for monitoring.

The Overwhelming Abundance of Oldsquaws

For each year of study in the central Alaska Beaufort when sufficient data were available, oldsquaws represented about 93% of all birds seen during aerial sampling from early June through late September (Table 1, Fig. 2). In fact, oldsquaws seen on-transect, i.e., within 400 m of the survey aircraft, during aerial sampling comprised over two thirds of all birds seen both on and off-transect throughout the survey area in all years of sampling (Table 1, Fig. 2). These results are especially significant considering that sampling effort over the years, as constrained by funding limitations, has varied considerably. For example, 7 surveys were conducted in 1977 spanning the period 5 June to 23 September with average coverage of about 55 km^2 per survey (Appendix 1). Ten surveys were conducted in 1978, 5 in 1979, 6 in 1981, and 5 in 1982 with daily survey coverage ranging from 64.88 to 120.32 km^2 (Appendix 1). On the other hand, in each of 1980, 1983 and 1984 only one survey was conducted, and that was during the peak of the male oldsquaw molt period, in late July or early August. Areal coverage during these surveys ranged from 72.73 to 136.88 km^2 (Appendix l).

Thus, notwithstanding inconsistent sampling efforts among years, the dominance of oldsquaws during all surveys underscores the overwhelming

Table 1. Numbers and percentages of oldsquaws counted during aerial surveys in nearshore waters of the central Alaska Beaufort Sea, 1977-1989.

Category*	Survey Year									
	1977	1978	1979	1980	1981	1982	1983	1984	1989	All Years
Numbers										
1	20695	111594	28598	22777	30597	31927	-	21998	102968	371154
2	58310	141801	36157	27826	48711	46964	6144	28399	110975	505287
3	94461	215199	49456	37549	65768	66794	-	33987	138729	701943
4	104318	231307	54049	38364	71104	69775	-	34972	149408	753297
Percentages										
5	90.55	93.04	91.50	97.88	92.50	95.73	-	97.18	92.85	93.18
6	55.90	61.30	66.90	72.53	68.51	67.31	-	81.20	74.28	67.08
7	21.91	51.86	57.83	60.66	46.52	47.80	-	64.72	74.22	52.88
8	19.84	48.24	52.91	59.37	43.03	45.76	-	62.90	68.92	49.27

* 1 = No. of oldsquaws on-transect only on barrier island transects during all surveys
2 = No. of oldsquaws on-transect on all transects during all surveys
3 = No. of oldsquaws on+off transect on all transects during all surveys
4 = No. of all birds of all species on+off transect on all transects during all surveys
5 = Cat. 3/Cat. 4
6= Cat. 2/Cat. 4
7= Cat. 1/Cat. 3
8 = Cat.1/Cat.4

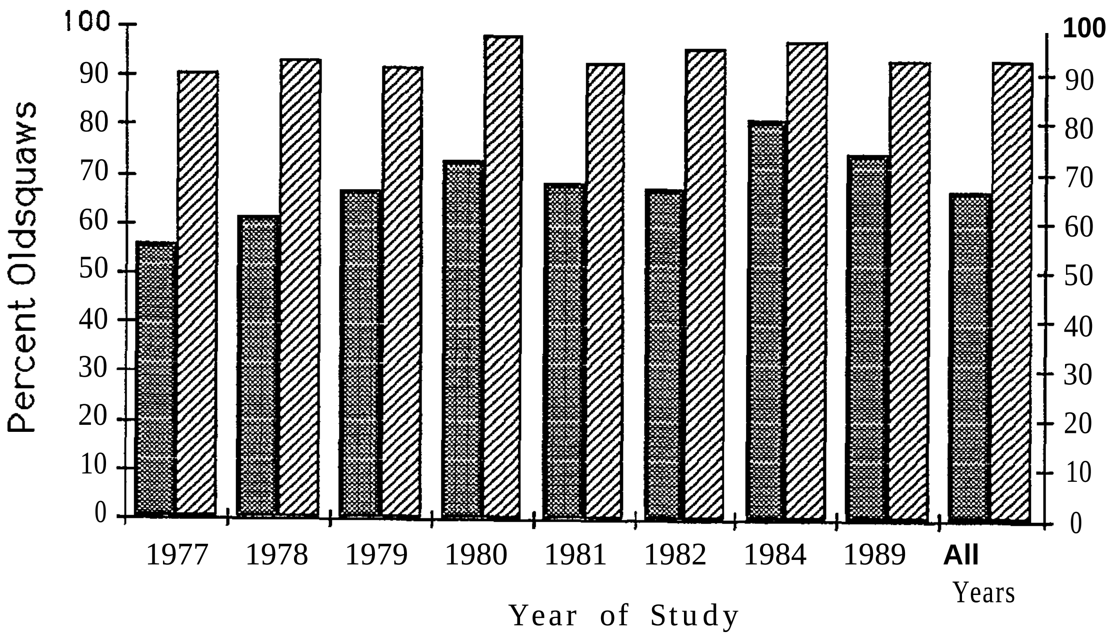

Figure2. Oldsquaw sightings as a percentof all waterbird sightings in the central Alaska Beaufort Sea, 1977-1989. Histograms represent the percentage of waterbird sightings that were oldsquaws, considering (1) on-transect birds only (stippled bars), and (2) on+off transect sightings (hatched bars).

abundance and widespread distribution of the oldsquaw duck in nearshore Beaufort environments throughout the open water period.

Study Areas

The Tones-Return Islands Industrial Area

The terms-of-reference identified the Jones-Return islands chain, west of Prudhoe Bay, Alaska, as the Industrial study area for this monitoring program (Fig. 3). These islands have remained relatively undeveloped over the past two decades during the course of oil and gas exploration on the adjacent mainland tundra, although there has been significant industrial activity in nearshore waters in the general area.

The West Dock (ARCO) causeway (Fig. 3), on the west side of Prudhoe Bay (USACE 1984), was constructed in 1974-1975 and subsequently has been used every summer as the major marine docking, loading and unloading facility in support of the Prudhoe Bay oil and gas fields. This causeway was extended in 1980 as part of the waterflood project (USACE 1984).

Three artificial oil well drilling islands, Seal, Northstar, and Sandpiper islands (Fig. 3), were constructed several km offshore from the Jones-Return islands during 1981-1985 (Johnson 1983). Drilling or associated activities have occurred on some of these islands up to the present.

Thetis Island, located about 5 km west of the Jones Islands, was used as a major gravel stockpile, staging site and construction area during summer 1983 for the Mukluk oil well drilling project in offshore Harrison Bay (Johnson 1983).

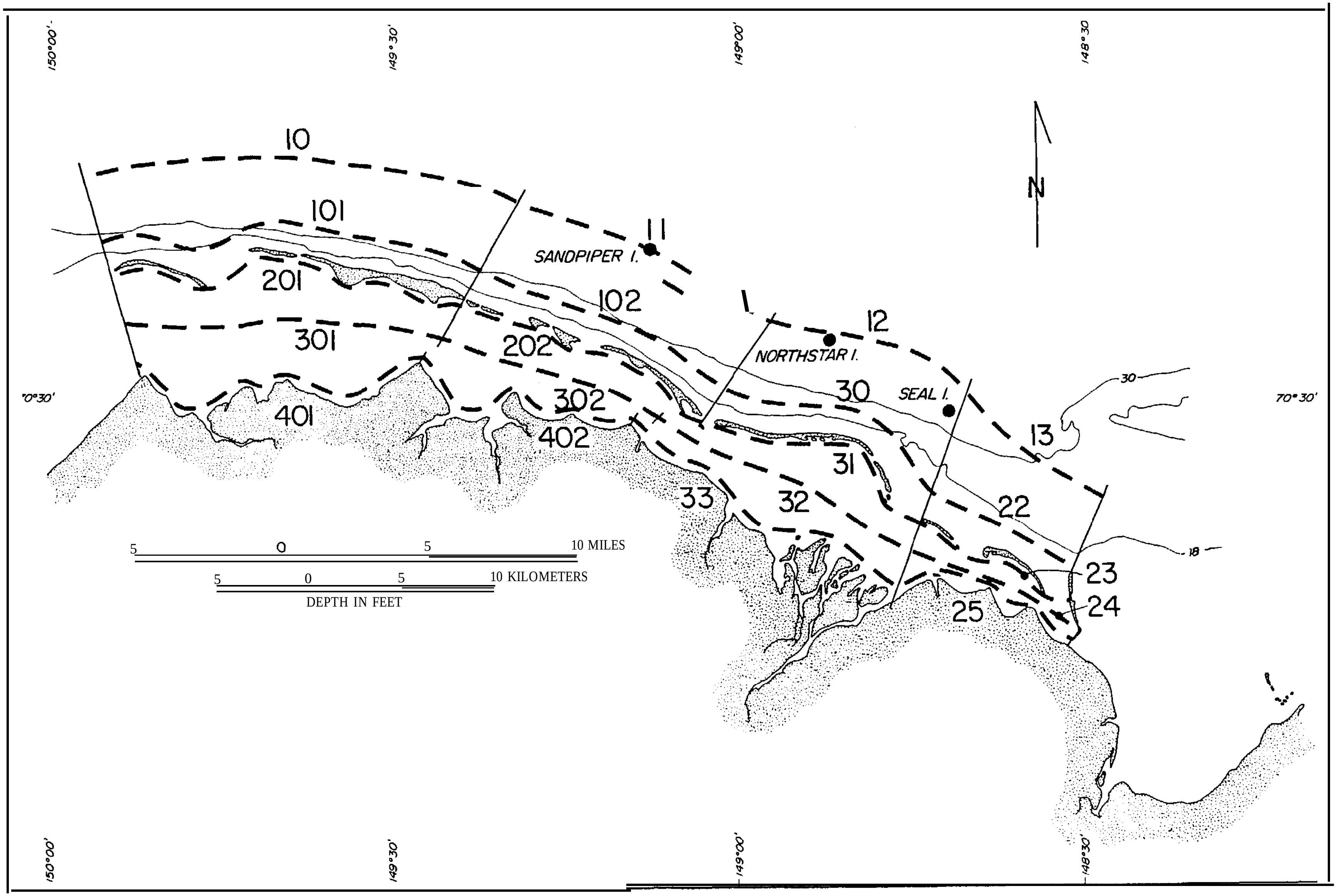

Figure 3. Industrial study area in the Jones-Return islands area, central Alaska Beaufort Sea. The West Dock (ARCO) Causeway is at the far western ends of transects 23 through 25.

No major permanent facilities have been constructed on the Jones or Return islands, but biological and physical scientific investigations with associated boat, aircraft and ground-based activities, have occurred in the area annually since 1977. Although the lagoons adjacent to the Jones and Return islands (Simpson and Stump Island lagoons, respectively, Fig. 3) are shallow (3 m maximum), they are traversed irregularly by low-flying aircraft and small boats traveling along the coast. The deeper waters seaward of the Jones and Return islands also are traversed irregularly by boats, ships and aircraft.

Aside from opportunistic aircraft overflight data collected in Simpson Lagoon during summer 1977 (Johnson 1978), there are virtually no data on the number of aircraft or boats traveling through the Jones-Return islands area. Neverthess, the Industrial study area is located immediately adjacent to the major oil and gas developments on the North Slope of Alaska, and is no doubt influenced by a higher level of day-to-day industry-related activities than are immediately adjacent areas.

The Stockton-Maguire-Flaxman Islands Control Area

The Stockton-Maguire-Flaxman islands area, located about *50* km east of the Industrial area, was selected as the Control area for the present monitoring study (Fig. 4). The area is similar in structure and size to the Industrial Area, it is used extensively by oldsquaws and other waterbirds, and there is a base of historical aerial survey data for use in statistical analyses and comparisons.

Furthermore, the Control area in situated along a part of the Beaufort Sea coast where very little coastal or nearshore industrial activity has occurred. Although several oil wells have been drilled during winter on or

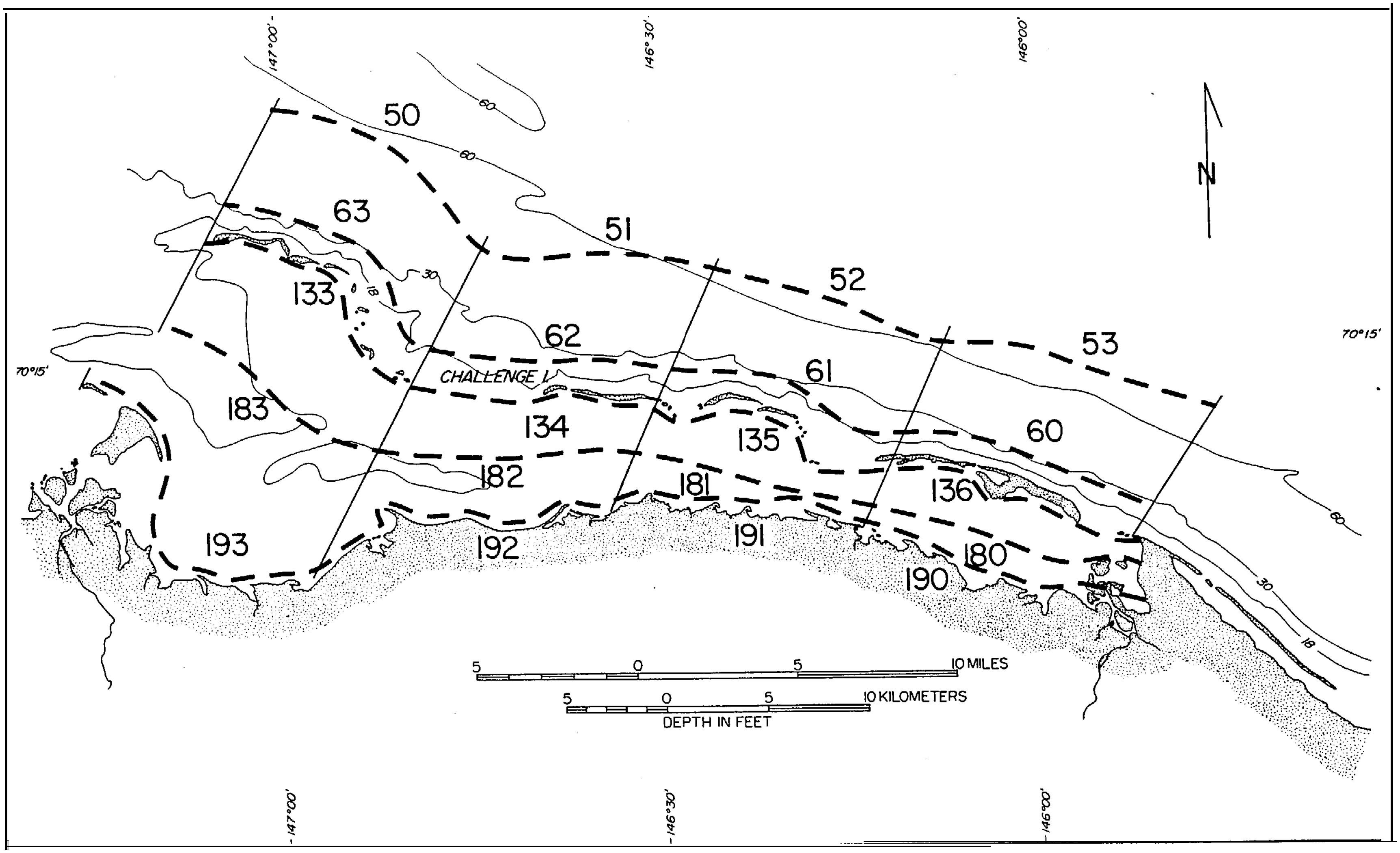

Figure4. Control study area in the Stockton-Maguire-Flaxman islands area, central Alaska Beaufort Sea.

adjacent to a few of the islands in the Control area (e.g., Challenge Island), and on the adjacent mainland tundra (e.g., Pt. Thomson), the area is relatively pristine and undisturbed compared to the Industrial study area.

An Assessment of Variables Affecting Oldsquaw Densities

Application of the most powerful practical analytical methods is important in order to identify and isolate the potential effects of various environmental factors, including industrial effects, on oldsquaws and other waterbirds. Useful procedures include multiple regression analysis, particularly for unstructured historical data, and multiway analysis of variance (ANOVA) or covariance (ANCOVA) for well-structured data.

Several variables have important and relatively well understood effects on the numbers and distributions of oldsquaws present in the two study areas. In designing a long-term monitoring method, it is critical to take account of the natural factors that affect the numbers of oldsquaws seen. In the following paragraphs we present an evaluation and discussion of these factors. We include a re-analysis of presently available data in order to evaluate the nature and importance of the influences of various natural factors on oldsquaw densities.

Analysis Considerations

Industrial effects on waterbirds can affect their densities on either a large or a small scale. Large-scale effects probably can best be detected by comparing year-to-year trends in numbers or densities within areas with much industrial activity vs. otherwise-similar areas with little industrial activity, i.e. in this study, the Industrial vs. Control study areas. Small-scale industrial effects may occur whether or not any large-scale effect is evident. They may be identified by comparing densities on transects subject to varying levels of human activity after allowing for natural factors known to affect waterbird densities.

Although our aerial survey transects are normally similar in length, the actual transect length that can be surveyed may vary because of fog, glare, or some other factor. Consequently, results of aerial surveys must be converted to densities (numbers per unit area) to allow meaningful comparisons.

When compiled into frequency distributions, numbers and densities of marine birds tend to be strongly skewed to the right. As a result, the differences between observed and predicted numbers or densities (i.e., the residuals) are also skewed to the right. This necessitates a logarithmic ($\ln(X+1)$) or similar transformation in order to meet the assumptions of parametric analyses such as multiple regression analysis and analysis of variance (Zar 1984, Draper and Smith 1981). The "+1" term is necessary to avoid problems when no birds are seen on a transect, since In(O) is undefined; $\ln(0+1)=0$.

Even after a "$\ln(X+1)$" transformation, the data may not adequately meet the normality and homogeneity of variance (homoscedasticity) assumptions of certain parametric analyses. The accuracy of these assumptions must be checked by analysis of residuals when parametric methods are implemented (Zar 1984; Draper and Smith 1981).

Densities of oldsquaws and other birds observed during aerial surveys of the study area are known, mainly through previous LGL studies, to be affected by date within the season, time of day, proximity to barrier island, wind, ice conditions, and wave height (Johnson 1985, Johnson and Richardson 1981). Because of these real variations in numbers present, along with variations in sightability, there are large survey-to-survey variations in numbers of birds seen. During past surveys this variability has been minimized insofar as possible by the use of standardized sampling procedures over all years of aerial surveys.

Many of the factors affecting densities of oldsquaws along the coast of the Beaufort Sea have already been investigated. Based on those results, we selected relevant predictor variables for use in a multiple regression analysis. This analysis allows us to determine quantitatively which variables are most important in controlling the dependent variable, i.e., the densities of oldsquaws recorded on aerial survey transects. Multiple regression analysis is the most useful and appropriate statistical technique for analyzing the historical aerial survey data relevant to waterbirds in the study areas. It does not require a rigidly structured survey design of the type necessary for other powerful but less flexible analysis procedures, such as analyses of variance and covariance. The historical survey data, although collected using standard LGL aerial survey procedures (Johnson and Richardson 1981, Troy and Johnson 1982), have been collected in different combinations of areas and date ranges during different years. They are more amenable to multiple regression analyses than to a multi-way analysis of variance (Zar 1984). In the following paragraphs we discuss the procedures and variables used in our multiple regression analyses of the historical data.

Multiple Regression Analyses

The multiple general linear hypothesis (MGLH) approach provided by SYSTAT (Wilkinson 1987) was selected for conducting the multiple regression analyses and analyses of residuals required for the design phase of this study. The SYSTAT version of MGLH is a powerful, thorough, and relatively easy to use statistical package that requires a modest knowledge of statistics and a rudimentary knowledge of the programming language BASIC.

Each of the relevant predictor variables (independent variables) selected for use in the multiple regression analysis of oldsquaw density (dependent variable = DENSTRAN) on transects in the study areas is discussed below, and a brief rationale is given for its inclusion in the analysis.

1. Year of study. Earlier studies (Richardson and Johnson 1981), and subsequent analyses in the present study (Appendix 1), have shown that densities of oldsquaws on the same transects in the Jones-Return islands area varied considerably from one year to the next. Consequently we have included a YEAR term in the analysis. Transects surveyed in 1977, the first year of standard LGL surveys in the Jones-Return islands, were assigned a value of 1 and transects surveyed in 1989 were assigned a value of 13; intervening years were assigned corresponding values.

2. Time of the year (day of the season) that sampling occurred. Previous studies clearly showed that use of nearshore habitats by oldsquaws and other marine birds was highest during the summer open water period (Johnson and Richardson 1981). Numbers and densities were consistently high during the month-long period from mid-July to mid-August when male

oldsquaws congregate in nearshore lagoons to molt (Johnson 1985; Garner and Reynolds 1986:129). Consequently we have included a DAY term in the analyses, with 1 June assigned a value of 1 and 30 September a value of 122; intervening days were assigned corresponding values. The pattern of increasing and then declining densities of oldsquaws over the June through September period (Fig. 5) suggested that, as a minimum, a second-order date term ($Date^2$) also should be included in the multivariate analysis; thus we have included DAYTRAN as an additional term.

3. Time of day that sampling occurred. Long-term, continuous observations in the Jones-Return islands area clearly showed that, in undisturbed situations, molting oldsquaws exhibited a 24-hr cycle of distribution, abundance and behavior in barrier island-lagoon habitats (Fig. 6; Johnson 1982a, 1983, 1985). The TIME term in our analyses is the local time (Alaska Daylight Time) recorded at the start of the aerial survey of each transect. Again, it was expected that a modified approach might be necessary after inspection of residuals from the preliminary analysis with a single TIME term.

4. Water depth in the sampling area. Studies of feeding behavior of oldsquaws in the Jones-Return islands area indicated that they feed preferentially in the shallow nearshore lagoons in the area. These studies also showed that the invertebrate prey of oldsquaws is most abundant in the deeper parts (2-3 m) of the lagoons, and that oldsquaws feed more efficiently (have more food in their stomachs) in areas of the lagoon where invertebrates were abundant (Table 2; Johnson 1984; Johnson and Richardson 1981). For each transect, the DEPTH term used in our analyses is the average

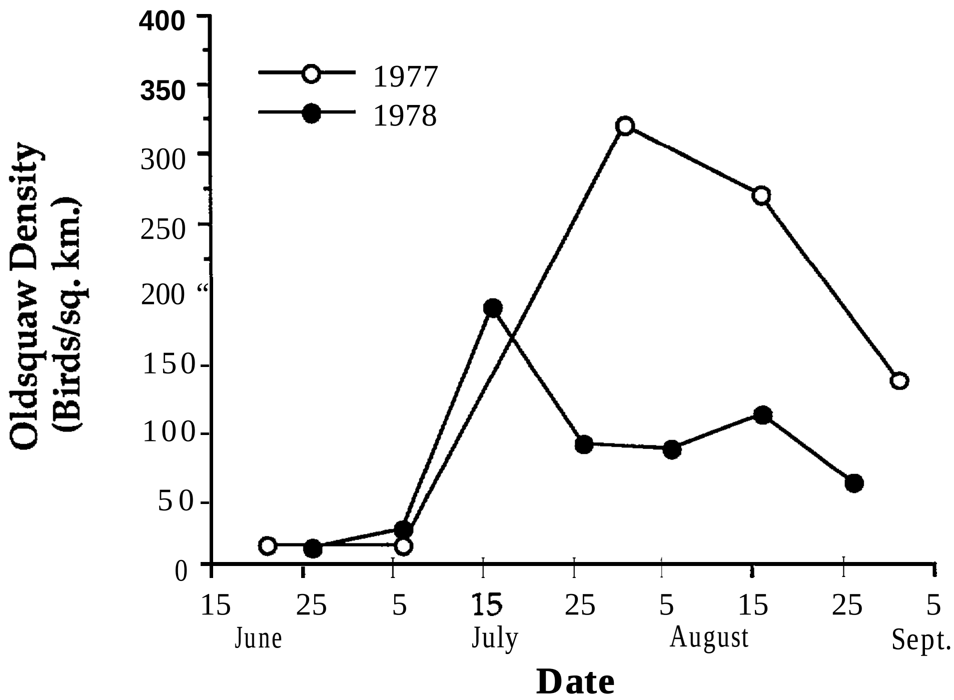

Figure 5. Densities of oldsquaws in the Jones-Return islands area of the central Alaska Beaufort Sea, June to September 1977 and 1978.

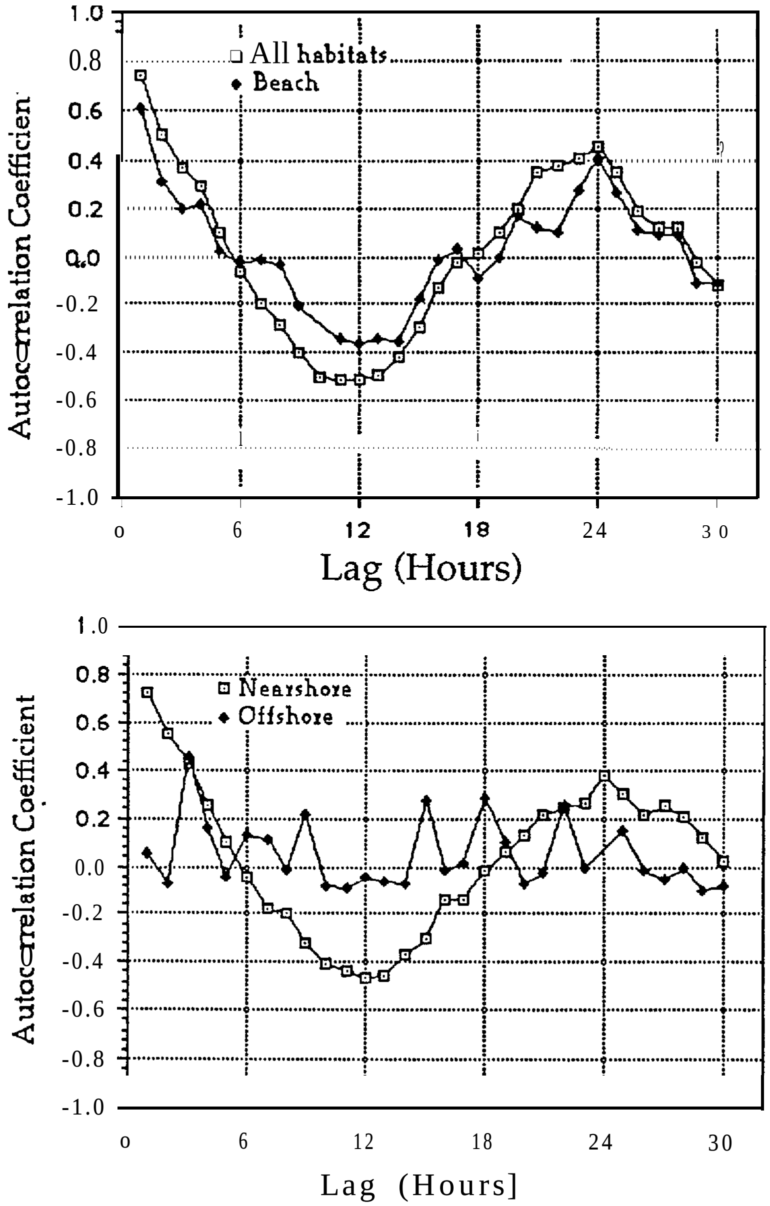

Figure 6. Results of autocorrelation analyses of numbers of oldsquaws in various barrier island-lagoon habitats during four 30-hr cycles (120 hrs) of activity when oldsquaws were relatively undisturbed and when waters were calm. Lag (hour) correlations of numbers of oldsquaws in beach, nearshore and total lagoon habitats showed a 24-hr period; numbers in offshore habitats showed little periodicity (from Johnson 1982a).

Table 2. Summary of water depths and feeding efficiencies of oldsquaws in the Jones-Return islands area, Beaufort Sea, Alaska (Johnson 1984c).

		1977	1978	
		All Oldsquaws (n=77)	Feeding Oldsquaws (n=81)	All Oldsquaws (n=108)
Water Depth (m)		2.09±0.178	2.07±0.179	2.05±0.172
Spearman Correlation of prey in Stomach vs. prey in Habitat (g. dry wt.)		All Inverts.	Mysids	Amphipods
	Spearman r	0.68	0.34	0.02
	P	<0.001	0.02	0.1
	n	25	25	25

water depth measured in feet from U.S. NOAA, Nat. Ocean Survey Nautical Charts 16045, 16046, 16061, 16062 at 5 equidistant points along the transect.

It was expected that a modified approach might be necessary after inspection of residuals from the preliminary analysis using the original DEPTH term. In fact, the transformation $1/DEPTH^2$ was necessary to provide a new term (DEI?TRAN) that corrected for the observed non-linear relationship between DEPTH and DENSTRAN. Water depth was not used in the final multiple regression analysis, however, because of its direct relationship (redundancy) with HABITAT, whose definition is, in part, based on water depth.

5. Location of the sampling area along an east-west axis. Although oldsquaws congregate in barrier island-lagoon habitats along the entire Beaufort Sea coast where suitable habitat exists, earlier studies showed that densities of oldsquaws were consistently higher in some parts of the study area than in others (Johnson and Richardson 1981; Johnson 1984b; Garner and Reynolds 1988). As a consequence, we have included an interval scale WESTEAST term in our analyses. The entire study area was subdivided into 12 longitudinal segments. Transects situated at the far west end of the Industrial Area (transects 10, 101, 201, 301 and 401) were assigned a value of 1. Other transects situated farther east in the Industrial Area were assigned values of 2, 3 or 4, depending on their "east-west" positions in the study area. Transects in the Control Area were assigned values of 9 through 12 depending upon their east-west position; transects 53, 60, 136, 180, and 190, i.e., those situated farthest east, were assigned a value of 12.

6. Proximity of sampling area (transect) to a barrier island. Earlier studies, and preliminary analysis of data in the present study, indicated that the numbers and densities of oldsquaws and other waterbirds were generally greater on transects close to barrier islands than on other transects more distant from barrier islands (Tables 1 and 3, Fig. 7) (Johnson 1985; Johnson and Richardson 1981; Brackney et al. 1985:350).

This distribution is thought to be the result of a functional response by the birds, especially during the energetically demanding molt period when virtually all oldsquaws are flightless. During this period the birds seek areas (1) with abundant and available food, (2) that provide shelter from prevailing winds (mainly from the NE), and (3) that provide relatively protected shorelines where they can roost out of the water (Johnson 1983, 1985). In nearshore habitats in the Arctic National Wildlife Refuge oldsquaws also showed a very strong avoidance of unprotected ocean and open lagoon habitats, and showed significant preferences for protected barrier island habitats (Brackney et al. 1985:350).

We have included two predictor variables in our analyses that relate to proximity of the sampling area to a barrier island. One measure (DIST) is the absolute value (on a continuous scale) of the average distance of the transect from a barrier island; DISTRAN is the transformed version of DIST. The average is computed from 5 perpendicular measurements taken at equidistant points along the length of the transect, the same points where water depths were measured.

The other measure of proximity of the sampling area to a barrier island is HABITAT, which is represented by 4 dummy variables (Wilkinson 1987; Draper and Smith 1981). The dummy variables (one less than the total five habitats) were automatically computed by SYSTAT during the multiple

Table 3. Summary of correlation coefficients of oldsquaw densities on individual transects in the Jones-Return islands area vs. overall density of oldsquaws in the same area during the same surveys.

Transect No.	Habitat	r	n
23	Barrier Island	0.279	17
31	Barrier Island	0.811	13
201	Barrier Island	0.853	19
202	Barrier Island	0.536	18
22	Marine	0.437	10
101	Marine	0.444	18
102	Marine	-0.266	18
24	Mid-Lagoon	-0.177	17
32	Mid-Lagoon	-0.293	12
301	Mid-Lagoon	0.151	18
302	Mid-Lagoon	0.106	18
401	Mainland Shore	0.482	16
402	Mainland Shore	0.272	16

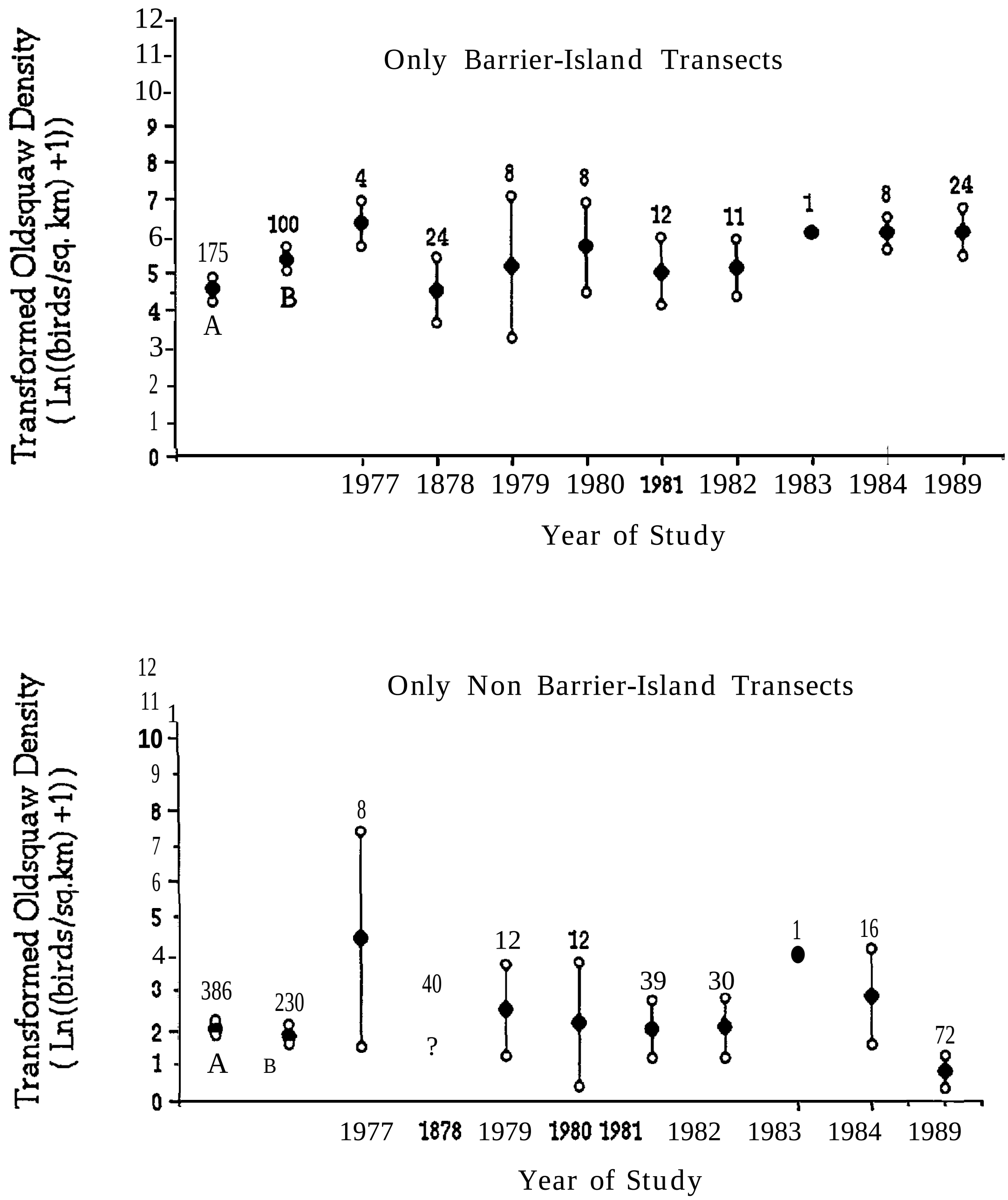

Figure 7. Mean ±95% C.I. (confidence intervals) of transformed densities [ln(1+density)] of oldsquaws on all barrier island and non-barrier island transects during the molt period (15 July-15 August) in the central Alaska Beaufort Sea, 1977-1989. Also shown, at left, are values for all years combined during the molt period (B), and during all periods (A: 5 June to 23 September). Sample sizes (number of transects) are given for each set of surveys.

regression analyses. Analysis results were combined into a single F-ratio (with 4 d.f. rather than the usual 1 d.f.), reflecting the overall habitat effect. Ultimately, this was the only measure of habitat used in the multiple regression analyses; DIST and DISTRAN were thought to be redundant with HABITAT.

7. Wind speed and direction in the sampling area during the sampling period. Prevailing winds in the central Beaufort Sea area during the summer are easterly, northeasterly or northerly (Fig. 8; Brewer et al. 1977). Various studies have indicated that the density of oldsquaws on different transects in the Jones-Return islands area was significantly related to the speed and direction of wind during aerial and ground-based sampling (Fig. 9; Johnson 1985; Johnson and Richardson 1981). Consequently, we included several measures of wind speed and direction as predictor variables in our initial multiple regression analyses.

Wind speed and wind direction were included as separate predictor variables. Wind speed (WSPD) was measured in km/hr, and wind direction was measured on several scales--a 360° (true) scale (WDIR) and on an ordinal octant scale (ORDWND) with the prevailing octant (NE = 45° ± 22.5°; see Fig. 8) assigned a value of 1 and the opposite octant (225° ± 22.5°) assigned a value of 5; winds from the three remaining pairs of octants were assigned values of 2 through 4, in accordance with the extent of their deviation from the prevailing northeasterly octant.

Two other continuous measures of wind speed and direction were included as predictor variables, the northern and northeastern components of wind (NCOMWND and NECOMWND, respectively). These variables

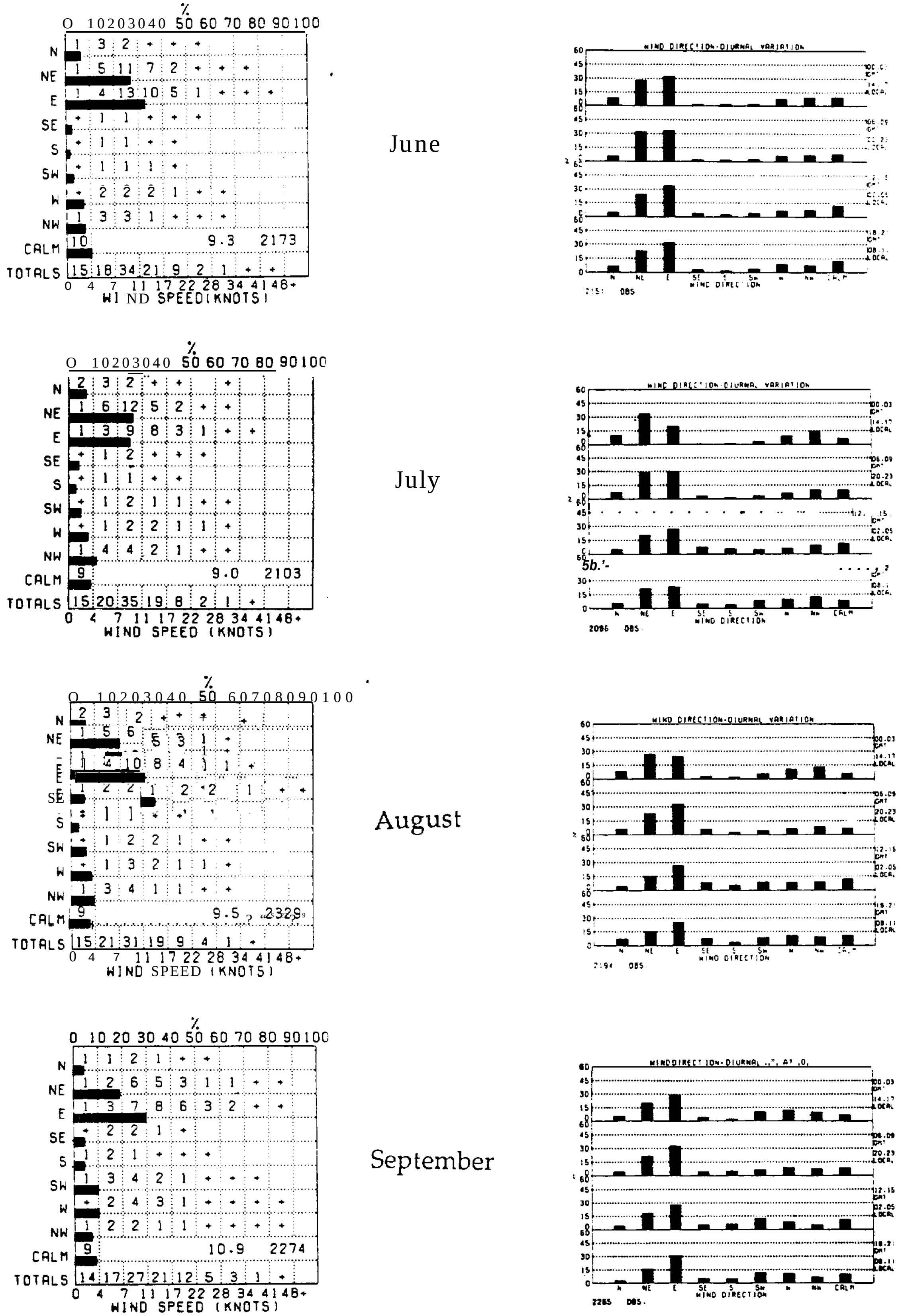

Figure 8. Average wind speeds and directions for June through September at a coastal site (Oliktok Point) in the central Alaska Beaufort Sea (from Brewer et al. 1977).

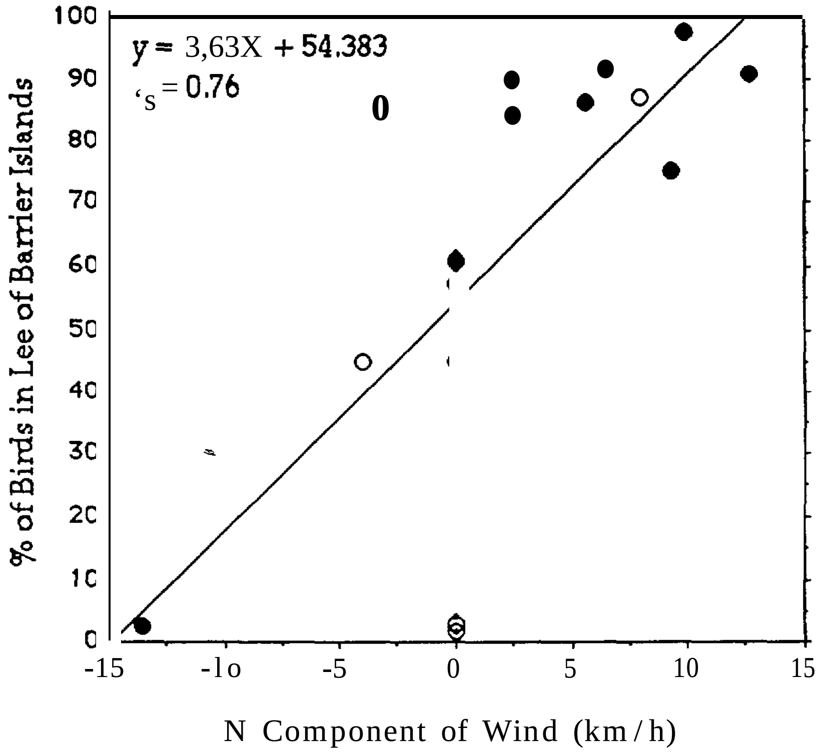

Figure 9. Relationship between wind direction and speed (N component of wind) and the location of oldsquaws in the Jones Islands area, Alaska, during 1977 and 1978. N component of wind = (windspeed in km) x (cosine wind direction in degrees true); negative N component is S component. O and . are 1977 and 1978 data from Johnson and Richardson (1981).

combine wind direction and speed into a single measure. The two wind components were computed as follows:

NCOMWND = Cosine direction (^{0}) x wind speed (km/hr)

NECOMWND= Cosine direction (^{0}- 45) x wind speed (km/hr)

Negative N and NE components are S and SW components, respectively.

In our preliminary statistical analyses we used all of these variables to find which ones were significantly associated with the dependent variable (transformed oldsquaw density = DENSTRAN). In the final regression analysis we used only WSPD and WDIR. Residuals were examined to ensure that relationships were linear.

8. Percent ice-cover on-transect in the study area during the sampling period. Earlier studies indicated that densities of oldsquaws during the male molt period in the Jones-Return islands area are higher in lagoon habitats where there is consistently less ice on-transect than in areas seaward of the barrier islands (Johnson and Richardson 1981). Consequently, we included the measure of estimated percent ice on-transect (ICECOVER) as a predictor variable in the multiple regression analysis.

9. Wave height on-transect in the study area during the sampling period. Wave height on transects in the sampling area is directly related to the direction and speed of wind, which were previously discussed as separate predictor variables (see above). Nevertheless, wave height, regardless of wind speed and direction, has a significant influence on the detectability of oldsquaws and other marine birds swimming on the water, and thus affects

the apparent density of oldsquaws recorded on-transect. Wave height estimates (WAVEHT) were available from the historical surveys as well as for 1989.

10. Study Area. Two distinct sampling areas are surveyed in this study (Industrial and Control areas). For the multivariate analysis this categorical measure (AREA) is represented by a dummy variable (Wilkinson 1987; Draper and Smith 1981) representing the particular study area within which the transect is located.

Analytical Assumptions and Data Transformations

Several important assumptions of parametric MGLH statistical procedures must be satisfied for the procedures to be valid. These assumptions are (1) that the residuals (observed densities minus those predicted by the regression model) are normally distributed, (2) that the variability in residuals is unrelated to values of any predictor variables, i.e., the homogeneity of variance or homoscedasticity assumption, and (3) that the relationships between the dependent and independent variables are linear.

Ecological data often do not meet these basic assumptions, but transformations of the data often will correct problems. Numbers and densities of marine birds, and thus the residuals, tend to be strongly skewed to the right, as discussed earlier. This necessitates a logarithmic transformation (ln (X + 1)) in order to meet the assumptions of parametric analyses such as multiple regression analysis and analysis of variance (Zar 1984). Consequently, all oldsquaw density values (1977-1989) used in this study have been log transformed.

Similarly, the residuals associated with the relationship between ice cover on-transect and oldsquaw density were not normally distributed. Consequently this independent variable was also log transformed ($\ln(1 + X)$) to satisfy the assumptions of normality.

Preliminary analyses also indicated that the relationship between oldsquaw density and water depth was not linear. Inverse-square ($1/X^2$) transformations of these data were necessary to satisfy the requirements of MGLH analysis procedures. Similarly, scattergram plots of oldsquaw density vs. date indicated a non-linear relationship and indicated that a second order date term (X^2) should be added to the multiple regression model. All other independent variables appeared to meet the requirements of parametric and general linear modelling statistical procedures.

Results of Multiple Regression Analyses

Two separate multiple regression analyses were conducted. The first analysis was for the complete study period using all available data for all transects surveyed on any date (5 June to 23 September = days 1 to 123) during all years of study. Only complete sets of data, i.e., no missing variables, were used for this analysis (n = 474 transects).

A second analysis was conducted using data only from the oldsquaw molt period (I5 July to 15 August = days 46 to 76) during all years of study. Data from this period were almost exclusively from molting (i.e., flightless and therefore relatively sedentary) male oldsquaws, and excluded highly mobile birds that could still fly from one transect (or study area) to the next in a relatively short time. As in the previous analysis, only complete sets of data were used (n = 275 transects).

Many different multiple regression models were examined for both sets of data (complete season and molt period). The first few analyses included all possible predictor variables and selected interaction combinations, including variables that were closely inter-related with others and thus redundant. In the final analyses, however, redundant and/or irrelevant variables were omitted and the models were composed of only appropriately transformed and distinct predictor variables that were relevant to the hypotheses being tested.

Complete Study Period (5 June to 23 September)

The multiple regression analysis for all dates and years (complete study period) showed a relatively strong relationship between the predictor variables and the density of oldsquaws (n = 474 transects, multiple R = 0.76; Appendix 2); several of the predictor variables were significantly and statistical y related to the dependent variable DENSTRAN (Table 4). Nevertheless, only about half (multiple R^2 = 0.57) of the variation in oldsquaw density for the open water period was accounted for by the predictor variables used in the present multiple regression analysis. This suggests that measurement error and the existence of several other unmeasured variables inside and/or outside the study area may also have an influence on the numbers and densities of oldsquaws in the study area. We discuss this topic in more detail later in the report.

The predictor variables which had a significant influence on oldsquaw density (DENSTRAN) over the entire study period (5 June to 23 September) during all years in both study areas were HABITAT (F-ratio = 4.22, nominal P = 0.002), HABITAT*TIME (F-ratio = 13.62, nominal P = <0.001), DAY (F-ratio =

Table 4. Summary of results of multiple regression analyses of historical oldsquaw density data (DENSTRAN) collected in the Jones-Return islands area, Beau fort Sea, Alaska, during 1977 to 1989*.

		5 June to 23 September (n= 474)			15 July to 15 August (n= 275)		
Independent Variables	Degrees of Freedom	Coefficients	F-Ratios	Nominal P Values	Coefficients	F-Ratios	Nominal P Values
CONSTANT	N/A	-2.179	N/A	N/A	-1.269	N/A	N/A
YEAR	1	-0.038	1.30	0.256	-0.076	3.30	0.070
DAY	1	0.097	19.62	<0.001 **	0.099	0.17	0.678
DAYTRAN	1	-0.001	0.15	0.702	-0.001	0.08	0.774
TIME	1	0.001	1.02	0.314	0.001	1.34	0.248
WESTEAST	1	-0.054	0.52	0.474	-0.128	1.89	0.170
WSPD	1	0.003	0.00	0.965	4.025	0.17	0.680
WDIR	1	-0.003	0.83	0.362	-0.007	2.86	0.092
WDIR*WSPD	1	0.000	1.68	0.196	0.000	7.44	0.007**
ICETRAN	1	-0.047	0.11	0.745	0.374	1.51	0.220
WAVETRAN	1	-0.376	6.81	0.009**	-0.457	6.63	0.01 1**
HABITAT(1-4)	4	-0.229; 3.91 1; -4.105; 1.513	4.22	0.002*'	-1 .645; 3.244; 2.415; 3.258	1.58	0.180
AREA	1	-0.010	0.00	0.989	-1.121	1.38	0.241
YEAR*AREA	1	0.016	0.12	0.732	0.153	7.36	0.007**
HABITAT(1-4)*DAYTRAN	4	-0.000; 0.000; 0.000; 0.000	2.38	0.051	0.000; 0.000; -0.000; -0,001	1.20	0.310
HABITAT(1-4)*TIME	4	0.002; -0.003; 0.002; -0.002	13.62	<0.001 **	0.002; -0.003; 0.001; -0,000	7.34	< 0.001**
HABITAT(1-4)*WSPD	4	0.004; -0.006; 0.062; -0.044	2.01	0.093	0.003; 0.004; 0.034; -0.077	1.44	0221
HABITAT(1-4)*WDIR	4	0.001; 0.000; -0.002; 0.004	0.91	0.457	0.003; 0.003; 4.002; 0.000	0.67	0.616
HABITAT(1-4)*WAVETRAN	4	0.227; 0.329; -0.754; 0.080	2.36	0.052	0.359; 0.198; -1 .030; 0.210	1.16	0.329
HABITAT(1-4)*ICETRAN	4	-0.357; 0.001; -0.051; 0.119	2.32	0.057	-0.322; 1.181; 0.195; -0.892	3.66	0.007**

* Refer to Appendices 2 and 3 for a complete listing of the regression models and analysis of variance tables.

** Nominal P values ≤ 0.050 were considered to be statistically significant.

19.62, nominal P < 0.001), and WAVETRAN (F-ratio = 6.81, nominal P = 0.009) (Table 4 and Appendix 2). It is notable that several of the statistically significant predictor variables were associated with habitat. Significantly higher densities of oldsquaws were recorded in barrier island or lagoon habitats (Appendix 2).

In fact, the largest proportion of oldsquaws were counted on lagoon transects, and especially those situated along barrier islands. This association was noted in previous studies in the area, and is thought to be related to an adaptation by oldsquaws to seek shelter in areas away from rough water, ice and predators, and in areas where food is abundant and highly available (Johnson 1985; Johnson and Richardson 1981).

The statistically significant relationship between DENSTRAN and the interaction term HABITAT*TIME was one the most striking results of the multiple regression analysis (Table 4; Appendix 2). As mentioned earlier, previous studies have indicated that oldsquaws show a significant diel pattern of abundance in the study area (Johnson 1983). Significantly more birds have been recorded near barrier islands late in the day when aerial survey conditions (especially sightability) are often best, i.e., when the birds are aggregated near leeward barrier island shorelines to roost and rest. Oldsquaws often roost along leeward lagoonside barrier island shorelines for extended periods during the molt (Johnson 1982a,b; 1983; Johnson and Richardson 1981).

Similarly, the statistically significant relationship between DENSTRAN and WAVETRAN indicates that significantly higher densities of oldsquaws are sighted on transects in relatively calm waters. This relationship is probably partly a reflection of improved sightability of birds in calm waters.

The other important and statistically significant relationship affecting oldsquaw density (DENSTRAN) was DAY of the season. This relationship is a reflection of the increasing density of oldsquaws on transects in the study area as the open-water season progresses.

Molt Period (15 July to 15 August)

Results of the multiple regression analysis of data collected only during the oldsquaw molt period (15 July-15 August) were very similar to those for the overall study period. There was a strong relationship between five of the 19 predictor variables and the density of oldsquaws (n = 275, multiple R = 0.83, Appendix 3). Over two-thirds (multiple R^2 = 0.68) of the total variation in oldsquaw density was accounted for by the variables and interaction terms used in the present multiple regression analysis. Although this situation is better than the one described earlier for the complete study period, it remains possible that, aside from measurement error, there are unmeasured variables inside and/or outside the study area that may influence the numbers and densities of oldsquaws in the study area. As mentioned above, this topic is covered in more detail later in the report.

Although HABITAT was an important indirect predictor of oldsquaw density during the molt period, there were several other significant predictors of oldsquaw density not observed in the earlier analysis, including the interaction term YEAR*AREA (F-ratio = 7.36, nominal P = 0.007) and WSPD*WDIR (F-ratio = 7.44, nominal P = 0.007) (Table 4). These results, and those indicated by the sign associated with the correlation coefficients indicate that the density of oldsquaws in the Control area has changed (increased) over the 9-year period of study, and that the combination of wind speed and direction has a strong influence on oldsquaw density in the study area, as described earlier (see Appendix 3)

The relationship between habitat and oldsquaw density was indirect; the interaction terms HABITAT*TIME (F-ratio = 6.34, nominal P <0.001) and HABITAT*ICETRAN (F-ratio = 3.66, nominal P = 0.007) indicated strong correlations between oldsquaw density (DENSTRAN) on transects in lagoon habitats (especially those along barrier islands) and the time of day and the amount of ice recorded on-transect (see Appendix 3).

It is notable that there was not a direct statistically significant relationship between oldsquaw density (DENSTRAN) and the habitat category (HABITAT) during the oldsquaw molt period, as there was during the complete June to September study period. But the statistically significant relationship between DENSTRAN and the interaction term HABITAT*TIME was the most striking result of the multiple regression analysis, and implicated habitat as a significant factor in determining oldsquaw density in the overall study area.

As mentioned earlier, previous studies have indicated that oldsquaws show a significant diel pattern of abundance in the study area (Johnson 1983). Significantly more birds have been recorded near barrier islands (Habitat 1) late in the day when aerial survey conditions (especially sightability) are often best, i.e., when the birds are aggregated near leeward barrier island shorelines to roost and rest. Oldsquaws often roost along leeward lagoonside barrier island shorelines for extended periods during the molt (Johnson 1982a.b; 1983; Johnson and Richardson 1981).

Similarly, the statistically significant relationship between DENSTRAN and the interaction term HABITAT*ICETRAN indicates that significantly higher densities of oldsquaws are sighted on transects in barrier island-lagoon habitats (especially those near barrier islands) with reduced ice cover. Although this variable relates to the sightability of birds on the water, it also relates to environmental conditions that may influence the behavior of the birds, as discussed earlier. Presumably there is improved sightability of birds on the water in areas of reduced ice, as well as a presumed preference by oldsquaws for habitats with reduced ice, i.e., barrier island lagoon rather than off shore marine habitats.

Analysis of Residuals

As pointed out by Draper and Smith (1981:141), the residuals or "errors" in a regression analysis are "...the differences between what is actually observed, and what is predicted by the regression equation–that is, the amount which the regression equation has not been able to explain." When conducting a regression analysis it is necessary to make various assumptions about these errors, namely that (1) they have a mean of zero, (2) they have a constant variance, and (3) are distributed normally. The assumption of normality is required for conducting F-tests (Draper and Smith 1981) associated with the regression analysis.

Both Draper and Smith (1981) and Zar (1984) provide comprehensive discussions of residuals analyses related to multiple regression analysis. In general, however, it is recommended that plots of residuals against predictor variables are useful and necessary to ensure that the various assumptions of regression analysis have not been violated.

We have conducted a thorough analysis of residuals of the data used in the multiple regression analyses. Appendix 4 shows plots of residuals vs. all of the various untransformed and transformed predictor variables used in the multiple regression analyses described earlier. A satisfactory plot is one in which the vertical scatter of points is relatively even across the range of each predictor variable, as plotted on the X axis. For example, the scatter of points in the plots of YEAR and TIME were satisfactory following the criteria given in Draper and Smith (1981), Zar (1984) and Wilkinson (1984). However, the plot of residuals against the untransformed DEPTH data showed a type of problem typical when an important variable has been omitted from the regression model. The inclusion of transformed depth data (1/X2) in one of our preliminary regression analyses provided a satisfactory remedy for this problem. (Note: DEPTH and DEPTRAN were not used in the final regression model because of redundancy with HABITAT.) Similarly the residuals plot of a second order date term (DAY^2) indicated that the inclusion of this variable in the analysis was appropriate in addressing the problem of non-linearity.

The remaining plots of residuals, with the exception of the one for ICE, indicated no serious violations of assumptions required for multiple regression analysis. And after making appropriate ln(X + 1) transformations of the ICE data (ICETRAN), the residuals plots of this predictor variable were also satisfactory (see Appendix 4). No plots of residuals of categorical variables are given because dummy variables were used in these cases. In effect, the use of dummy variables ensures that the assumptions of regression analysis (and analysis of variance) are satisfied.

In summary, after appropriate transformations of data (see Appendix 5), and inclusion of appropriate higher order terms for some variable (e.g., date), the analysis of residuals indicated that the assumptions necessary for conducting a multiple regression analysis were not violated.

Influences That Mav Affect Oldsquaw Density

The overall amount of variation explained by the predictor variables in the two multiple regression analyses was only about 57 percent for the complete study period, and 68 percent for the molt period. These values are less than hoped for and indicate that, aside from measurement error, other important variables that were not measured may have substantial influences on oldsquaw distribution, abundance and density.

Most important, in past surveys there has been no provision for recording the level of human activity on transects, aside from the obvious presence or absence of a major structure, such as an artificial island, causeway, or drilling structure. Hence neither of the regression analyses conducted here accounts for any small-scale human effects on oldsquaw density.

Another major confounding factor is the degree to which the distribution and abundance of the oldsquaws may be determined by influences outside the study area, and therefore are not measurable in a local or regional monitoring program. This potential source of error may have a significant influence on the distribution, estimated abundance, and density of oldsquaws in both study areas. Most waterfowl are highly traditional in their behavior, e.g., they often nest, molt, migrate and over-winter in the same general area from one year to the next (Hochbaum 1955; Lokemoen et al. 1990). There is uncertainty, however, about whether oldsquaws OCCUpy the same barrier island-lagoon systems from one year to the next, or about the degree of movement of birds from one nearshore area to the next. Radio telemetry studies of oldsquaw movements in barrier island-lagoon habitats in the Arctic National Wildlife Refuge, Alaska, showed that molting oldsquaws moved an average distance of 0.69 km/day ±s.d. 1.29, and ranged from 0.01 to 3.85 km/day (Brackney et al. 1985). All movements of these radio-tagged oldsquaws were local and within or adjacent to the lagoon in which the birds were originally captured.

Nevertheless, the 500 km long chain of barrier islands, lagoons, bays and large freshwater lakes along the Beaufort Sea coast from Point Barrow, Alaska, to Cape Parry, NWT, Canada, are all used by marine waterfowl, especially oldsquaws, but also smaller numbers of scoters (*Melanitta* spp.), red-breasted mergansers (*Mergus senator*), and Pacific eiders during the post-breeding molt period. There is little or no information on how various environmental and biological factors interact to determine which areas may be used by molting oldsquaws from one year to the next. The molt migration by oldsquaws is generally westward along the Beaufort Sea coast in late June through mid-July (Johnson and Richardson 1982). Influences such as (1) amount of ice present and timing of ice break-up in a particular barrier island-lagoon system, (2) oceanographic conditions along one part of the coast in relation to another, and (3) weather during the molt migration (e.g., presence of favoring tailwinds), may all influence whether some or all birds from one particular area may be attracted to a lagoon during the molt period. The scale of such events is too large to be accounted for in a monitoring program conducted along only one part of the Beaufort Sea coast; a coast-wide study would be necessary to determine if there are large-scale changes in abundance of oldsquaws (or any other of the widely distributed species) in one part of the Beaufort Sea relative to another.

We suspect that factors such as these not included in the regression analyses may have had a significant influence on the numbers and densities of oldsquaws recorded during past years in central Alaska Beaufort Sea barrier island-lagoon systems. Although some of these influences are difficult if not impossible to measure, it is possible to design a monitoring program so that much of the remaining variability could be accounted for. The implementation of such a program is described in the following section of this report.

IMPLEMENTATION OF A MONITORING PROTOCOL

This section of the report deals with the implementation of a monitoring protocol for Beaufort Sea marine waterbirds. This phase of the study relies heavily on information provided by the preceding analyses of historical data and other information taken from the literature relevant to this project.

Design Considerations for Implementing a Monitoring Protocol

Results from earlier studies (Johnson and Richardson 1981, Troy et al. 1983) and from the multivariate analyses presented above have indicated that some of the variation in oldsquaw density may be attributable to sighting conditions that are influenced by wind, sea state, ice cover, sun glare, etc. Additional variation may be attributable to local variations in human activities within the areas designated as either Industrial or Control. It is important to account for the causes of as much of this variation as possible in order to maximize the power of the statistical procedures used to identify the presence and magnitude of any industrial effects, either broad-scale (i.e., Industrial Area vs. Control Area) or fine-scale (transect-to-transect within one or both study areas). Consequently, in future analyses associated with the Beaufort Waterbird Monitoring Protocol, an additional independent variable, one that has been absent from all earlier analyses, needs to be included. This variable is "Levels and types of industrial activities in the study areas during the sampling periods."

Industrial activities can affect waterbird densities on either a large or small scale. Large scale activities in the Industrial area during the open water period, e.g., intense boat or aircraft activities and associated disturbance to birds, could result in fewer birds using this area. Although such a result has not yet been documented in the Beaufort Sea, if it were to occur it would be detected in our analysis of covariance; the YEAR x AREA interaction term would show a statistically significant difference.

Small-scale temporal and spatial effects on oldsquaw distribution, abundance and behavior have been demonstrated in at least two previous studies on Thetis Island (Johnson 1982a, 1984), located about 5 km west of the Jones Islands, but few other investigations in nearshore environments have shown an unequivocal relationship between the density of any Beaufort Sea waterbird species and industrial activities in adjacent nearshore areas. In particular, the area around the West Dock (ARCO) causeway was investigated extensively during the Waterflood Environmental Monitoring Project (Troy and Johnson 1982; Troy et al. 1983; Troy 1984). Those studies found no significant adverse effects on oldsquaws, the focal species in those investigations, that could be attributed to the 1980 causeway extension. It should be remembered, however, that the ARCO causeway was originally constructed in 1974 and 1975, well before any of the historical data used in the Waterflood studies were collected. As a consequence, any effects of the original causeway construction on waterbird distribution, abundance and behavior probably would not have been detectable in later studies because of a lack of pre-construction (pre-1974) oldsquaw data.

Other than the West Dock causeway, few major permanent industrial activities have occurred in nearshore environments in the central Beaufort Sea. The three small artificial drilling islands (Seal, Sandpiper and Northstar islands) seaward of the Jones-Return islands were constructed during winter 1982-1984 and were not specifically monitored for possible effects on waterbirds during the following open water periods. Thus, there are no relevant historical data on waterbird use of those areas before and after development.

The recently constructed Endicott causeway lies in an area along the mainland shoreline in a part of the Sagavanirktok River delta where no natural barrier islands or lagoons are present and where few marine waterfowl or seabirds were abundant. As mentioned in an earlier section (see "The Oldsquaw as the Focal Species"), the birds that historically have used this area of the central Beaufort Sea, primarily common eiders, brant, snow geese, and glaucous gulls, are unsuitable candidates for a nearshore monitoring program of the type specified in this study.

Nevertheless, we have prepared an ordinal scale measurement of industrial activity (1 through 5) that can be assigned to each transect depending upon the type and amount of activity that has recently occurred or is presently occuring in or immediately adjacent to the transect (Table 5). It will be of critical importance to establish and maintain a line of communication with key industry and agency people in research, regulatory and monitoring capacities to insure that relevant information on human activities in the two study areas is documented and included in the monitoring program.

This additional independent variable will provide the basis for determining the degree to which oldsquaw density may be affected by large- and small-scale industrial activity in the Jones-Return islands area.

Long-term studies of fish distribution, abundance and movements in the Alaska and Canadian portions of the Beaufort Sea have shown that

Table 5. Ordinal scale for recording levels and types of industry activities that may affect oldsquaw densities in the Jones-Return islands area, Beaufort Sea, Alaska.

Activity Index	Activity Level	Type of Industry Activity
1	Nil	No human activity or disturbance in area of interest.
2	Low	Infrequent aircraft overflights, boat traffic or human activity on the island or in the water during the summer open-water period in the area of interest.
3	Moderate	Regular aircraft overflights, boat traffic or human activity on the island or in the water during the summer open-water period in the area of interest.
4	High	Intense aircraft overflights, boat traffic or human activity, and/or spillage of low levels of toxic materials (oil, fuel) and associated clean-up activities during the summer open-water period in the area of interest, and/or serni-premanent structures established in the area with frequent presence of humans and associated activity.
5	Extreme	Major spill of toxic materials (oil, fuel) and associated clean-up activities during the summer open-water period effecting a large area, including the area of interest, and/or permanent structures established in the area with near-continuous presence of humans and associated activity.

prevailing winds and resulting oceanographic conditions along the coast have a profound effect on the distribution of most anadromous fish species, especially the ciscoes and broad whitefish (LGL 1989; LGL et al. 1989; LGL 1990). The principal oceanographic features which control the distribution and abundance of these fish in the nearshore zone are temperature and salinity patterns. These factors are controlled primarily by prevailing wind direction and speed which cause coastal upwellings. These upwellings transport food (marine invertebrates) into the nearshore zone and restrict the distribution of freshwater flowing from the terrestrial system into a narrow band of brackish water along the coast. This brackish zone is preferred habitat for most of these species of anadromous fish.

It is possible that the physical factors described above also influence the distribution, abundance, and movements of oldsquaw ducks, which similarly occupy nearshore brackish-water habitats (barrier island-lagoon habitats) along the Beaufort Sea coast. We recommend that factors such as seasonal upwelling potential and/or season mean wind speed and direction (LGL et al. 1990) also be considered when interpretating year to year variations in numbers of oldsquaws using habitats in the Industrial and Control study areas.

Sampling Procedures

The need for powerful analytical approaches in the monitoring program dictates the use of field sampling procedures that satisfy the requirements of the analysis methods. We have organized the future sampling in such a way to obtain data for the following spatial and temporal categories:

Two study areas (Industrial and Control).

Five distinct habitats within each of the two study areas. These habitats are: (1) barrier island habitats with transects sampling the area within 0.40 km lagoonward of the barrier island; (2) mid-lagoon habitats with transects located midway between lagoonward shorelines of barrier islands and mainland shorelines; (3) mainland shoreline habitats with transects sampling the area within 0.40 km lagoonward of the mainland shoreline; (4) inshore marine habitats with transects located 1.5 km seaward of the barrier islands; (5) offshore marine habitats with transects located 5 km seaward of the barrier islands.

Four transects within each habitat x area combination.

Four 5-day sampling periods during each year.

Three survey dates within each 5-day sampling period.

This sampling hierarchy will provide the replicated and structured data necessary to isolate the effects of the variables known to affect bird densities. The experimental design is compatible with the powerful ANOVA and ANCOVA statistical procedures that we will use to separate the effects of year, date, time, east-west location, study area, habitat, amount of ice, wind, wave height, level and type of human activity, etc.

Although we did not originally recommend that mainland shoreline habitats be sampled in our proposed monitoring design, we now recommend that an additional set of four transects along the mainland shoreline in both study areas should be added to include this area in the monitoring protocol. Relatively large numbers of oldsquaws (and other marine birds) use mainland shoreline habitats sporadically during the proposed sampling periods, especially in the Control study area where various small lagoons and spits along the mainland coast provide suitable sheltered habitats, especially for oldsquaws. Furthermore, birds in these mainland coastal areas could well be the first affected by industrial activities; development probably will occur along mainland shoreline areas before it does so on the adjacent barrier islands or in offshore areas.

We also recommend that linear distance of the transect to a barrier island (DIST and DISTRAN) and water depth (DEPTH and DEPTRAN) not be included as covariates in the ANCOVA procedures for structured data. Water depth is closely correlated with distance from shore. Distance from shore is part of the definition of HABITAT type. Thus these variables would be redundant and confounding covariates if they were included in the proposed analyses.

Schedule of Surveys

Based on the results of earlier studies and on the results of the regression analyses described above, the appropriate period for surveys of marine birds in both Beaufort study areas (Industrial and Control) is from mid-July until late August or early September, i.e., during the oldsquaw molt period. We recommend that four separate surveys be conducted during this period at about 8- to 10-day intervals, starting on about 15 July. Within each 8-10 d interval, all transects should be surveyed three times. Given the typical frequency of bad weather, it will typically require 5 days to complete three surveys. This will provide replicate surveys during each sampling period; these replicates are essential for variance computations.

The multiple regression analysis indicated that the time of day that the surveys are flown is positively correlated with oldsquaw density in specific lagoon habitats. Hence, we recommend that aerial surveys be conducted as late in the day as practical, i.e., at least as ate as 1700 h ADT, as long as survey conditions are adequate.

Similarly, there were significant negative correlations between wave height and amount of ice recorded on transects versus the density of oldsquaws recorded. Based on these results we recommend that surveys not be conducted during periods of high winds (> 10 kts) and heavy ice (≥ 50%). Since we have recommended that monitoring surveys start on 15 July, after ice break-up has occurred in the marine system, influences of heavy ice-cover should be less of a problem in this study than during other years when some surveys began as early as 5 June. Beaufort Sea lagoons are usually ice-free by mid-June.

Data Recording

Recording of aerial survey data will be standardized according to procedures established during a set of structured test surveys conducted in early August 1989. With several important modifications, these surveys were similar in design and execution to standard LGL surveys of barrier island-lagoon and adjacent habitats that have been conducted since 1977 (Johnson and Richardson 1981). During the 1989 test surveys we adopted 30-second time-period intervals for recording the number of birds on and off transect and for recording an array of information about the survey conditions and prevailing environmental conditions. Variables to be recorded include amount of ice on and off transect, wave height, glare on the water surface, wind speed and direction, habitat type or proximity to barrier island or other structure, apparent type and level of human activity on and off transect, and any changes in any particular variable noted during the course of the survey.

Information will be collected for all species of birds and mammals observed on and off the transects. Surveys are flown with two prime observers at an altitude of 45 m and at a ground speed of 180 km/hr. Transect width is 400 m, 200 m on each side of the aircraft; climometers are used to calibrate distances from the aircraft. Observers are trained to count large numbers of birds in dense concentrations through a series of poppy-seed trials, Varying quantities of poppy-seeds are distributed on a sheet of paper by an independent examiner isolated from the observers. The observers are then allowed 8 seconds to estimate the number of seeds on the paper. The trial is repeated 5-10 times with different numbers and patterns of seeds. After the final trial, the scores of each observer are tallied and compared with the actual number of seeds using Chi-squared techniques (observed-expected). These trials help the observer to accurately estimate large numbers of birds in dense concentrations; furthermore, inherent biases in counting ability may also be detected and accounted for in corrected density computations.

During aerial surveys, tape recorders are used to record information about the birds, their habitats and environmental conditions during the survey. Data are later transcribed and coded onto standard coding forms that provide for accurate recording of all of the information described above. Data are key-entered and verified by data-entry professionals, and validation programs are run to isolate improbable or impossible combinations of data codes.

Linear and areal densities are computed for all species sighted on-transect during all surveys; linear densities are also computed for on+off-transect sightings. These data are then tabulated by species, year, date, time period, transect, and observer.

Analysis Procedures

The multiple regression approaches described in the preceding sections are optimum for examining historical data collected in a rather unstructured manner. However, greater statistical power and precision can be obtained by collecting future data in a more structured fashion. These data should be examined primarily by analysis of variance (ANOVA) and analysis of covariance (ANCOVA) methods.

The design presented in this study has the characteristics identified as optimal by Green (1979). In particular, it provides for both spatial and temporal control--two key requirements for this type of study. The sampling of a control area as well as an industrial area each year provides the spatial control. By sampling each area before as well as during major industrial development, we will also obtain temporal control. Both types of control are necessary in order to determine whether changes within the Industrial Study Area are directly attributable to the industrial activity. A change occurring in the industrial area when there is no parallel change in the Control Study Area can reasonably be assumed to be attributable to the industrial activity. In an ANOVA context, such a change is recognizable as a “significant interaction between the AREA term and the YEAR term.

In the present study, additonal factors besides AREA and YEAR must be taken into account in the analysis. These will include variations in waterbird density attributable to sampling period, time of day, habitat type, east-west position within the study area, wind and ice conditions during surveys, local variations in human activity, etc. Because the survey design will be precisely structured with regard to year, study area, sampling period, habitat, and transect, these can be identified as factors in an analysis of variance. Wind direction and speed, ice cover, wave height, human activity, and other unpredictable continuously-distributed variables will be best handled as covariates rather than as categorical factors. A measurement of human activity along each transect will be an important covariate; by considering this variable, we can assess the possibility of small-scale industrial effects on waterbird density at various locations within the Industrial or Control area.

Analysis of Variance and Covariance

In order to test the two null hypotheses presented at the start of this exercise (see “Background” section in the “INTRODUCTION”), i.e., to test whether there have been changes in densities of molting male oldsquaws in selected Beaufort Sea index area that may be attributable to industrial activities, we recommend a 5 factor–5 covariate analysis of covariance statistical approach. The 5 factors are year, area, sampling period, habitat and transect, and the 5 covariates are ice cover, wind direction, wind speed, wave height, and the measure of human activity (disturbance) on each transect; the replicates are the three separate days of surveys within each sampling period.

The ANCOVA Model

The assumptions needed to conduct an ANCOVA such as the one recommended here are discussed by Hui tema (1980), and are as follows:

1. Randomization, i.e., replicates are independent.
2. Homogeneity of within-group regressions, i.e., homogeneity of slopes in regressions of oldsquaw density *vs.* covariates (between transects).
3. Linearity of within-group regressions, i.e., linearity of slopes in regressions of density vs. covariates (between transects).
4. Statistical independence of covariate and treatment, i.e., the covariate measure (e.g., wave height, wind direction, etc.) does not effect the density of oldsquaws in a treatment level.
5. Fixed covariate values that are known or measured without error.
6. Normality of conditional response scores, i.e., oldsquaw densities are normally distributed after correction by the covariates.
7. Homogeneity of variance of conditional response scores, i.e., variation in oldsquaw densities is homogeneous after correction by the covariates.
8. Clearly defined treatment levels.

The ANCOVA model most appropriate and best suited to test for significant differences in oldsquaw densities over space and time is given in the following equation:

$$\text{Mean}+A+Y+YA+H(A)+YH(A)+P(Y)+AP(Y)+T(H(A))+YT(H(A))+\text{error}$$

Parentheses indicate that some factors are nested within others, e.g., H(A) is interpreted as habitat nested within area. Table 6 defines the five factors in this analysis and indicates which ones are fixed or random, and designates the appropriate levels of analysis. It also gives the expected mean square and "error" term for testing the statistical significance of each of the terms in the model.

The ANCOVA can be visualized as an ANOVA with the addition of covariates to help standardize the basic unit of analysis (i.e., the analysis cell = oldsquaw density on a transect in a habitat in a study area during a survey in a sampling period within a year). The ANOVA model is nested (sampling period within year, habitat within study area, transect within habitat) and factor effects are mixed, i.e., some are fixed and some are random. Year, area and period are fixed and interpretations of analysis results of these factors can only be extended to the levels tested (see Table 6). On the other hand, habitat and transect are considered random effects since they could have been defined in a variety of different ways to represent the spatial structure of the factor.

An important statistical consideration is that transects are "nested" within habitats and areas, not "crossed" (Zar 1984). Also, the same areas are sampled repeatedly; it is not possible in the protocol design recommended here to sample the two different study areas at the same time during each survey. One study area is sampled after sampling in the other has been completed. For these and other reasons, the "error" terms for the multi-way ANCOVA need to be specifically tailored to the recommended experimental design (see Table 6).

Because of the nested design and mixed (random and fixed) effects, variation between "habitats within areas", rather than the overall "residual mean square", is used as the error term for the test of study area effects (Table

Table 6. Expected mean squares and “error” terms to be used for tests of ANCOVA hypotheses associated with the temporal and spatial distribution of old squaw ducks in the central Alaska Beaufort Sea.

Terms*	Expected Mean Squares”*				Test “Error” Terms
A	residual error +	24*T(H(A)) +	96*H(A) +	480*A	H(A)
Y	residual error +	12*YT(H(A)) +	48*YH(A) +	480*Y	YH(A)
YA	residual error +	12*YT(H(A)) +	48*YH(A) +	240*YA	YH(A)
H(A)	residual error +	24*T(H(A)) +	96*H(A) +		T{H(A))
YH(A)	residual error +	12*YT(H(A)) +	48*YH(A) +		YT(H(A))
P(Y)	residual error +	120*P(Y) +			residual error
AP(Y)	residual error +	60*AP(Y) +			residual error
T(H(A))	residual error +	24*T(H(A)) +			residual error
YT(H(A))	residual error +	12*YT(H(A)) +			residual error

* Y= Year, A= Area (Industrial and Control), P=Sampling Period, H= Habitat, T= Transect. Year and Area are fixed factors with 2 levels of analysis (it is assumed here that there are only 2 years of structured data); Period is also a fixed factor but it has 4 levels of analysis. Habitat and Transect are both random factors; Habitat has 5 levels and Transects has 4 levels of analysis.

** Parentheses designate that factors are nested, e.g., H(A)= Habitat is nested within Area.

6). The year and year-area interaction pretested byusing the''interactionof yearand habitat within areas" as the error term. The effects of habitat are tested by using "transects within habitats and areas" as the error term. The effects of year-habitat interaction are tested by using the "interaction of year and transects within habitats and areas" as the error term. And finally, the "residual error" term is used to test the significance of all terms involving sampling period and transect (Table 6).

The expected mean squares (Table 6) were computed using the SYSTAT DESIGN module (Dallal 1988), following procedures outlined by Miller (1986). The covariates mentioned above are simply included as additive continuous terms in the analysis. Any significant interaction of a covariate and a year term or an area term should be included in the model.

The appropriate analysis of covariance (ANCOVA) procedures suggested by Bliss (1970) and Huitema (1980) are as follows:

1. Log-transform the density data in order to reduce the skewness inherent in such data.
2. Conduct the ANCOVA with the 5 covariates and 10 interaction terms with year and area. Interactions with the finer-scale temporal and spatial terms should be ignored since they are nested within year and area.
3. If any of the interaction terms involving covariates are not significant, then those covariate terms should be removed from the model. However, they should be removed sequentially in such a way that the term with the greatest P-value (least statistically significant) is removed first; the ANCOVA model is then rerun and the remaining interaction

terms are examined. This process is repeated until all statistically non-significant interaction terms have been removed.

4. Conduct the ANCOVA using the factors, covariates and interaction terms remaining after following the procedures outlined in 3.) above. Also conduct an ANOVA (no covariates), and an ANCOVA with only the human activity covariate so the overall effect of human activity (industrial disturbance) and the "environmental" covariates (wind, waves, ice) can be isolated.

The proposed three surveys of each transect during each sampling period in the field season will provide the replication necessary for the ANCOVA. The ANCOVA will identify how much of the variation in densities of oldsquaws is attributable to each factor, i.e., year, study area, sampling period, habitat, transect, and to each covariate, i.e., wind, wave height, ice cover, local human activity (disturbance). A single survey during each sampling period would not provide the replication or sample size required to distinguish some of these effects in the presence of the unavoidable natural variation of such data.

The significance of the interaction term between year and area, after allowance for other factors, will be the main test of the possibility of a large-scale industrial effect. Similarly, a significant interaction of area and period may also indicate an industrial effect, but such an interpretation may be confounded by other possible biological interpretations. The significance of the human activity covariate term will be the test for smaller-scale human effects.

Simple graphical presentations of these relationships can be used to explain the statistical results and make them clear to readers who are not especially knowledgeable about the statistical procedures. These graphical approaches would be especially useful in examining the effects of covariate interactions (i.e., non-homogeneous slopes). For example, one can plot the fitted covariate regression equation over the range of values ± 2 standard deviations from the mean, or one could use the more quantitative Johnson-Neyman technique (Johnson and Neyman 1936) to show graphically the effects of such interactions.

Potential Problems and Sources of Error

The degree to which the various analysis assumptions are met in this study is important in determining whether the proposed analysis procedures are appropriate and statistically valid. Earlier in this section we listed eight assumptions that should be satisfied (Huitema 1980) before analysis of covariance procedures are attempted. Most of these assumptions should be easily satisfied given the proposed structured experimental design. Several assumptions may be problematic, however, and those are discussed here.

Random ization ---The extent to which the replicate surveys are independent is probably the most critical of several possible problems. It is possible that replicate surveys flown within a 5-clay sampling period may not be independent of each other, i.e., the densities of oldsquaws seen on transects during one survey may be related to those recorded on the same transects during an earlier survey. Presently the amount of movement within a transect or from one transect or habitat to another by oldsquaws is unknown, thus the actual amount of interdependency of oldsquaw densities on transects or habitats among surveys is unknown.

One study (Brackney et al. 1985) did show that radio-equipped oldsquaws molting in barrier island-lagoon habitats in the Arctic National Wildlife Refuge (ANWR) moved as much as several km per day, with an average movement of about 0.7 km per day. Thus, it is possible that oldsquaws may move as much as 3 to 4 km or more over a 5-day survey period. Such movements indicate that oldsquaws may not remain on the same transect (or in the same habitat) for prolonged periods of time. Nevertheless, the extent to which birds move from one area to the next along adjacent sections of the Beaufort Sea coast is presently unknown. Consequently, the degree to which replicate surveys randomly sample populations of oldsquaws is also currently unknown.

In the present monitoring protocol we have recommended an ANCOVA approach to analyzing future data. We have also explored the possibility of using the 'repeated measures' (RM) design for analyzing structured data of the type collected in this study. Although the RM approach is much more complex when more than one covariate is involved, it would alleviate potential problems associated with independence of replicate sampling.

The RM model appropriate for this study would have the following structure:

MODEL: Mean Density+A+Y+YA+H(A) +P(Y)+AP(Y)

where A = Area

Y = Year

H(A) = Habitat within Area

I?(Y) = Sampling Period within Year

This structure defines habitat within a period, and area as the 'subject' which is measured by repeatedly sampling transects. Sampling is replicated each survey day.

The RM approach differs from ANCOVA in the following ways:

1. There are two possible levels of randomization, i.e., habitats and transects, rather than only one in ANCOVA (transects).
2. Transect measurements need not be independent in RM, contrary to ANCOVA where this is a very important assumption (as discussed above).
3. The replication in RM is for the entire survey, rather than for the treatment effects as in ANCOVA.
4. Transects are not nested within areas, as in the ANCOVA, but each subject is measured separately. Transects are defined similarly for habitats in each of the two study areas. Therefore, habitat and transect are 'crossed' in RM, but each is at a different level of randomization. This contrasts with the ANCOVA design where habitats are 'nested' within study areas.
5. RM is much more powerful in detecting changes in density than ANCOVA.

In most situations the RM procedure is easier than and superior to ANCOVA; the exception is when when several covariates are involved, as in the present case. Covariates in RM can only interact with the grouping factor (habitat). Therfore, if the covariate measurement did not change with transect, i.e., within a habitat and survey day, analysis would be straightforward. Unfortunately this is not the case in the present study--

covariates (amount of ice, wave height, level of disturbance, etc.) will probably vary within a transect, habitat, and survey day. Thus, the use of RM for the present situation involves a very complex statistical procedure (tedious building of the design matrix) that may be beyond the realm of practicality for the present study, especially given the uncertainty about the actual level of independence in sampling transects in the ANCOVA design.

Nevertheless, we are prepared to conduct analyses and compare results using the two approaches after the first full season of data collection. The comparison should help decide which of the two approaches is most appropriate for the present study.

Statistical Independence of Covariate and Treatment--- It is probable that some covariates (e.g., wave height, wind speed and direction, amount of ice on-transect) will be dependent on some treatment factors (e.g., habitat, study area, day). For example, offshore habitats may be more exposed to ice, and therefore transects in this habitat may have more ice than those sheltered by barrier islands. Similarly, transects in barrier island habitats maybe sheltered by prevailing northerly winds, thereby affecting wave height in this habitat compared to those more exposed in offshore areas.

Such relationships between the treatments and covariates violate a fundamental assumption of ANCOVA. We have attempted to alleviate this problem by recommending that surveys should not be conducted (or transect densities should not be included in analyses) when extensive ice may be encountered along transects or when winds over 10 kts and associated high waves may be encountered. Although these recommended restrictions may limit the number of surveys completed during a 5-day sampling period, they are clearly required to insure that analyses do not violate ANCOVA assumptions.

Measurement Error--- Measurement error is a common problem where variables such as the number of animals, percent ice cover, wave height, wind speed and direction, and other factors are estimated from a fast-moving aircraft. Such measurement error biases the strength of relationships among dependent and independent (predictor) variables (i.e., reduces the power of statistical tests), as mentioned earlier in our discussion of the multiple regression results.

We have attempted to reduce measurement error to the greatest extent possible in this study by using well-trained and experienced aerial surveyors. Furthermore, we have implemented training sessions designed to enhance the abilities of an observer to estimate the number of birds and other variables recorded along aerial survey transects (see discussion in following section). Regardless of these efforts, however, some measurement error is inherent in field investigations of this type and is bound to influence analysis design, results and interpretations. Great care and concentration are necessary during aerial surveys to insure that measurement error is reduced to a minimum. Final interpretations of statistical analyses need to take into account the possible effects of measurement error.

We recommend that after the first full season of data collection, a statistical power analysis (see Peterman 1990) be conducted to determine whether the level (replication and precision) of sampling is sufficiently intensive, too intensive, or overly intensive to detect differences in oldsquaw densities, and ultimately to test the null hypotheses formulated at the start of this study. Such an analysis is based on realistic estimates of the amount of variation (including measurement error) in the structured data to be collected in the monitoring program. The historical oldsquaw data are not suitable for such an analysis.

SUMMARY AND CONCLUSIONS

Analyses of 9 years of historical aerial survey data indicated that oldsquaw ducks represented on average about 93% of all birds of all species seen both on- and off-transect in the central Alaska Beaufort Sea. A very large proportion of oldsquaws recorded during aerial surveys in this area were near barrier islands. These results, along with similar results from studies in the Arctic National Wildlife Refuge (Garner and Reynolds 1986), and the 1983 MMS / NOAA sponsored workshop on monitoring the nearshore Beau fort Sea environment (Dames and Moore 1984), indicate that the oldsquaw is the best candidate for study in a monitoring program designed to detect and measure the effects of industry activities on marine birds and waterfowl in the Jones-Return islands area, Beaufort Sea, Alaska.

Correlation analyses indicated that densities of oldsquaws along barrier island transects best reflected overall densities of oldsquaws in the study area during the sampling periods. Other studies indicated that undisturbed oldsquaws showed a strong diel periodicity in behavior and abundance at barrier island locations near the Jones-Return islands, and that oldsquaw distribution near barrier islands was significantly related to wind speed and direction. The results of these and other studies helped in the selection of potential predictor variables for use in a multivariate statistical analysis designed to isolate the most important determinants of oldsquaw density on transects in the study area.

The relevant predictor variables (independent variables) selected for use in the multiple regression analysis of oldsquaw density (dependent variable = DENSTRAN) on transects in the study areas are as follows:

1. Year of study (YEAR).
2. Time of the year (day of the season) that sampling occurred (DAY and DAYTRAN).
3. Time of day that sampling occurred (TIME).
4. Water depth in the sampling area (DEPTH and DEPTRAN).
5. Location of the sampling area along an east-west axis (WESTEAST and WESTRAN).
6. Proximity of sampling area (transect) to a barrier island (DIST, DISTRAN, and HABITAT).
7. Wind speed and direction in the sampling area during the sampling period (WDIR, WSPD, ORDWND, NECOMWND, NCOMWND).
8. Percent ice-cover on-transect in the study area during the sampling period (ICE and ICETRAN).
9. Wave height on-transect in the study area during the sampling period (WAVEHT and WAVETRAN).
10. Study Area (AREA).

Earlier analyses and analysis of residuals of this multiple regression analysis indicated that some of the variables should be transformed to satisfy various assumptions of the parametric general linear modelling (GLM) statistical procedures used in this study.

The multivariate statistical analyses of oldsquaw densities on transects during the open-water season (5 June to 23 September) and during the peak period of molt by male oldsquaws (15 July to 15 August) over 9 years of study indicated that several variables and combinations of variables (interaction terms) were highly significant in predicting oldsquaw density on transects in the study area. In particular DAY, WAVETRAN, HABITAT, YEAR*AREA, TIME*HABITAT, HABITAT* ICETRAN and WDIR*WSPD were important (statistically significant) predictors of oldsquaw density (Table 4) in one or the other of the two analyses. HABITAT was a particularly important predictor variable, especially in combination with TIME and ICETRAN.

The results of the multiple regression analyses helped in the design and implementation of the future sampling program and in the formulation of a specific analysis of covariance (ANCOVA) model to analyze data collected in future surveys of the Industrial and Control study areas.

We have organized the future sampling in such a way to obtain data for the following spatial and temporal categories:

Two study areas (Industrial and Control).

Five habitat strata: (1) barrier island habitat (2) mid-lagoon habitat, (3) mainland shoreline habitat, (4) inshore marine habitat, and (5) offshore marine habitat. The mainland shoreline habitat is newly recommended to cover an area thought to be important for marine waterfowl.

Four transects within each habitat stratum and area.

Four 5-day sampling periods during each year.

Three survey dates within each 5-day sampling period.

This sampling hierarchy will provide the replicated and structured data necessary to isolate the effects of the variables known to affect bird densities. The experimental design is compatible with the powerful ANOVA and ANCOVA statistical procedures that we will use to separate the effects of year, date, time, east-west location, study area, habitat, amount of ice, wind, wave height, level and type of human activity, etc.

The design presented in this study has the characteristics identified as optimal by Green (1979). In particular, it provides for both spatial and temporal control--two key requirements for this type of study. The sampling of a control area as well as an industrial area each year provides the spatial control. By sampling each area before as well as during major industrial development, we will also obtain temporal control. Both types of control are necessary in order to determine whether changes within the Industrial Study Area are directly attributable to the industrial activity. A change occuring in the industrial area when there is no parallel change in the Control Study Area can reasonably be assumed to be attributable to the industrial activity.

In order to test the two null hypotheses presented at the start of this exercise, i.e., to test whether there have been changes in densities of molting male oldsquaws in a selected Beaufort Sea index area that may be attributable to industrial activies we recommend an analysis of covariance statistical approach. The factors are year, area, sampling period, habitat and transect, and the covariates are ice cover, wind direction, wind speed, wave height, and the measure of human activity (disturbance) on each transect; the replicates are the three separate days of surveys within each sampling period.

The ANCOVA model most appropriate and best suited to test for significant differences in oldsquaw densities over space and time is as follows:

Mean+ A+ Y+ YA+H(A) +YH(A)+P(Y)+AP(Y)+T(H(A))+YT(H(A))+error

Parentheses indicate that some factors are nested within others, e.g., H(A) is interpreted as habitat nested within area. The ANOVA model is nested (sampling period within year, habitat within study area, transect within habitat) and factor effects are mixed, i.e., some are fixed and some are random. Year, area and period are fixed effects, but habitat and transect are considered random effects since they could have been defined in a number of different ways to represent the spatial structure of the factor.

Because of the nested design and mixed (random and fixed) effects, tests of significance of the various terms and interactions in the analysis model are specific to the particular test, i.e., terms other than residual error are used in some instances as the actual “error” term in the test (see Table 6).

We have followed the appropriate analysis of covariance (ANCOVA) procedures, as suggested by Bliss (1970), Huitema (1980), and others. The ANCOVA will identify how much of the variation in densities of oldsquaws is attributable to each factor, i.e., year, study area, sampling period, habitat, transect, and to each covariate i.e., wind, wave height, ice cover, local human activity (disturbance).

As an alternative, we have also recommended that a Repeated Measures (RM) statistical analysis also be conducted after the first field season in order to compare this procedure with ANOVA analysis procedures, which may violate basic ANOVA assumptions. RM procedures are very complex when more than one covariate is involved, so this statistical approach will be used only if it is found that replicate sampling of aerial survey transects is found not to be independent from one survey to the next--a violation of basic ANOVA assumptions.

We anticipate that the best software package available to conduct the ANOVA and ANCOVA (and possibly Repeated Measures) procedures outlined above for the implementation phase of the monitoring protocol is Supernova (Gagnon et al. 1989). Supernova is a powerful and flexible micro-computer based general linear modeling (GLM) package of programs designed specifically for solving analyses of variance and covariance and related statistical models. Supernova also has a complete graphics interface which will allow a clear presentation of results in both tabular and graphical form. The availability of a user-friendly and well documented package of programs for use in a monitoring protocol of this type is an important aspect of the design. It reduces the time and expense necessary to write and execute computer programs for the complex analyses required, and it provides a common basis for newcomers to the project.

We are confident that the monitoring plan presented above is the most appropriate and statistically defensible approach given the present state of information. Nevertheless, it is inevitable that, after the first complete season of data collection and subsequent analyses, it will be necessary to modify some aspects of the field procedures or some of the analyses to further improve the study. For example, we recommend that a power analysis be conducted after the first year of data collection. Such an analysis of the structured data will provide the variance information necessary to determine how many years of study will be necessary (2, 4, 6) to detect a change in oldsquaw density with a specified degree of probability (e.g., 90%) (see Peterman 1990). This and other desirable modifications in the monitoring protocol will be documented and a complete rationale will be provided for their consideration in the study.

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APPENDICES

Appendix 1. Individual on-transect densities of oldsquaws on transects in the Jones-Return and Stockton-Maguire-Flaxman islands areas, central Alaska Beaufort Sea, 5 June to 23 September 1977 to 1989.

ɔpen sect Sep 977

Survey Date	Overall Study Area			Barrier Island Transect Nos. and Areas SamPkd (sa. km.)								Non-barrier Island Transect Nos. and Areas Sampled (sq. km.)						
1977-1989	Total Sq. km. On-transect	Total # Birds On-transect	Overall Dens. BirdsIsa. km	23	31	201	202	133	134	135	136	10	11	12	13	22	24	25
				4.40	5.64	8.80	6.00	5.72	5.72	572	5.72	9.48	6.16	5.52	5.60	4.00	4.40	5.09
5 Jun.77	54.84	3	0.05			0.00	0.00											
20 Jun.77	54.84	34	0.62			1.82	1.17											
5 Jul.77	54.84	745	13.58			24.09	31.00											
28-29 Jul.77	54.84	3s350	644.60			525.57	276.17											
15 Aug.77	28-32	18(X)1	635.63			912.73	758.33											
30 Aug.77	54.84	4287	78.17			106.82	24.67											
22 Sep.77	54.84	14937	27237			36.48	0.17											
23 Jun.78	75.04	107	1.43	16.36	Iii’	2.16	0.00										0.00	
5 Jul.78	114.72	3305	28.81	0.00	6.91	88.86	267.67	0.10	8.92	210	0.87						0.00	
15 Jul.78	75.04	32771	436.71	89.32	1751.95	1595.68	1164.00										0.45	
25 Jul.78	114.60	9695	84.60	0.00	468.79	318.07	240.00	24.65	0.00	45.45	181.64						0.00	
5-6 Aug.78	120.32	12141	100.91	37.50	29.29	24.20	27.17	11.19	4.90	438.81	646.85						37.50	
15 Aug.78	75.04	18307	243.%	94.32	355.32	1721.02	61.33										94.32	
25 Aug.78	114.6	19369	169.01	62273	550.00	557.84	19.17	13.81	249.30	967.66							2.73	
5-6 Sep.78	120.32	19951	165.82	24.09	253.72	37.61	317.50	121.15	15.03	230.59	771.33						60.36	
15 Sep.78	69.28	4393	63.41	35.00	0.35	11.14	100.33										74.32	
23 Sep.78	120.32	21762	180.87	367.27	13.12	3.75	0.33	133.92	1334.97	343.88	142.31							
22 Jun.79	75.04	388	5.17	19.32	44.68	3.52	1.00										0.23	
28 Jul.79	120.32	24539	203.95	0.45	1063.30	390.11	711.67	376.22	19.23	360.84	666.78						3.64	
Aug.-1 Sep.79	64.88	5560	85.70	6.14	239.54	73.98	86.00											
22 Sep.79	75.04	5670	75.56	18.18	58.69	271.93	17250										5.23	
2 Aug.80	120.32	27826	231.27	394.09	1084.57	745.57	444.50	307.89	17.54	469.30	330.53						0.00	
18 Jul.81	66.73	1775	26.60	15.91		106.36										1.50	23.87	0.17
29 Jul.81	72.73	10751	147.82	306.59		238.63	904.83									0.00	0.00	0.51
2 Aug.81	97.44	15267	156.68	145.91	310.28	646.82	456.00										149.10	
12 Aug.81	60.61	1090	17.98	69.77		11.93	92.66									0.00	1.37	0.00
29 Aug.81	7273	1432	19.69	227		88.18	53.00									12.25	13.87	0.00
11 Sep.81	72.73	19976	274.66	1639.77		118.53	77.13									13S.25	1469.09	371.21
18 Jul.82	96.69	3817	39.48	23.60	8260	137.84	7270									5.75	25.45	0.10
31 Jul.82	7273	9214	126.69	95.00		203.40	271.40									95.00	42.73	0.80
14 Aug.82	78.37	19416	247.75	86.50	531.40	800.70	744.90									89.25	10.23	1.20
28 Aug.82	96.69	5650	58.43	75.90	186.50	136.30	52.10									4.00	4205	40.40
23 Sep.82	96.69	8867	91.71	20.50	10.50	150.20	19.50									0.00	4.09	27.80
29 Jul.83	7273	6305	86.69	434.10														
8 Aug.84	136.88	28399	207.47	712.73	265.61	275.34	746.17	369.06	260.84	240..56	958.92					91.00	63.64	0.00
6 Aug.89	186.24	31304	168.08	87.05	1376.60	89.09	13.83	786.19	27203	664.34	1241.96	0.00	272	0.00	0.00	0.00	0.00	
8 Aug.89	186.24	35060	188.25	236.82	2074.82	791.02	512.17	629.72	19.76	254.02	1103.67	0.21	0.00	0.00	0.00	0.00	0.00	
9 Aug.89	186.24	44611	239.54	480.68	2039.36	6415.34	375.17	777.27	381.47	410.84	2196.68	0.00	1.79	0.00	0.00	87.50	7.95	
n =	38	38	38	31	24	37	36	12	12	12	11	3	3	3	3	14	30	11
Mean =	91.18	13738.82	153.15	198.64	533.32	320.34	252.67	295.93	215.33	369.03	749.23	0.07	1.50	0.00	0.00	37.25	75.64	40.20
s.d. =	37.84	12077.24	152.79	331.64	665.17	420.68	308.76	297.56	378.61	261.32	628.58	0.12	1.38	0.00	0.00	49.61	265.71	110.65
Cv. =	41.50	87.91	99.77	166.95	124.72	131.32	122.20	100.35	175.83	70.81	83.90	173.21	91.96	0.00	0.00	133.18	351.31	275.25

ee Figs. 3, and 4 for transect locations,

Appendix 1. Continued.*

Survey Date 1977-1989	30	32	33	50	51	52	53	60	61	62	63	101	102	301	302	401	402	180	181	182	183
Non-barrier Island Transect Nos. and Areaa Sampled (sa. km.)	5.64	5.76	6.92	5.36	5.36	5.36	5.36	5.40	5.40	5.40	5.40	8.76	5.68	6.%	5.12	7.24	6.28	5.60	5.60	5.60	5.60
5 Jun.77												0.00	0.00	0.00	0.00	0.00	0.48				
m Jun.77												0.00	0.00	0.00	0.00	0.41	1.27				
5 Jul.77												3.42	0.18	0.29	6.64	29.97	10.03				
28-W Jul.77												4.57	0.18	1133.62	532.23	389.78	615.45				
15 Aug.77																282.73	7.96				
30 Aug.77												0.11	8.10	183.76	193.75	107.73	16.08				
22 Sep.77												0.57	7.75	1060.63	846.68	133.70	299.52				
23 Jun.78		0.52										0.00	0.00	0.00	0.00	0.14	0.00				
5 Jul.78		11.63										0.00	0.35	5.60	5.27	3.45	0.48	27.82	81.61	0.00	
15 Jul.78		6.42										1.14	4.40	54.31	19.92	40.06	99.84				
25 Jul.78		3.47										0.80	22.01	46.70	111.91	28.59	5.52	4.46	8.93	0.00	0.00
5-6 Aug.78		7.99										0.00	0.53	57.04	72.66	0.00	0.00	18s.71	150.71	0.00	0.00
15 Aug.78		14.76										0.00	0.00	8.15	6.45	0.00	0.00				
25 Aug.78		53.99										31.05	77.82	34.20	33.59	0.00	1.59	1.07	0.00	0.00	0.00
5-6 Sep.78		38.37										9.93	35.21	10.63	15.04	0.14	0.00	313.57	1025.18	190.36	19.11
15 Sep.78												157.19	24243	19.25	44.92	2.07	12.26				
23 Sep.78		26.91										0.00	0.00	42.39	49922	158.56	102.87	444.29	59.82	0.00	157.90
22 Jun.79		2.60										0.00	0.00	0.00	0.00	0.00	0.48				
28 Jul.79		4.51										6.8S	0.00	102.73	177.34	41.71	0.32	19.11	78.75	21.43	0.00 .
31 Aug.-1 Sep.79												31.39	13.20	543.97	50.20	0.00	0.00				
22 Sep.79		31.35										6.51	29.40	0.43	7.81	68.78	146.02				
2 Aug.80		71.18										0.00	0.00	6.30	339.06	186.88	191.72	0.00	12.86	0.00	0.00
18 Jul.81												0.00	158.45	3223	67.58	6.49	8.76				
29 Jul.81												0.17	0.00	217.10	6272	0.00	0.32				
2 Aug.81		242.40										0.00	0.00	3s1 .70	138.30	74.90	49.70	6s.40	30.40	0.00	0.00
12 Aug.81												0.00	0.00	5.17	9.91	0.27	4.30				
29 Aug.81												7.08	0.82	8.05	17.97	0.00	0.00				
11 Sep.81												24.89	50.17	115.90	93.36	0.69	1.12				
18 Jul.82	2.36	72.92	2.30									0.00	0.18	47.99	8.79	4.90	5.90				
31 Jul.82												0.00	0.18	293.68	321.88	19.00	7.60				
14 Aug.82												1.14	0.00	0.29	38.09	0.00	0.00				
28 Aug.82	7.87	3.82	17.20									1.03	15.32	86.93	%.64	0.00	0.00				
23 Sep.82	0.20	72.92	2.30									0.00	0.18	47.99	8.79	4.90	5.90				
29 Jul.83																					
8 Aug.84	5.91	69.79	0.00									1.14	10.04	338.51	219.73	0.00	0.00	51.61	185.90	104.47	7.86
6 Aug.89	0.00	10.42		2.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.43	326.17			0.00	0.00	2%.96	0.00
8 Aug.89	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	79.02	0.59			4.46	17.86	21.61	0.00
9 Aug.89	1.3a	0.00		0.00	5.60	4.66	0.00	0.00	0.00	0.00	0.00	0.00	0.35	14.37	0.59			0.00	0.00	194.64	39.29
n =	7	21	4	3	3	3	3	3	3	3	3	36	36	36	36	34	34	13	13	13	12
Mean =	2.53	35.52	5.4s	0.93	1.87	1.55	0.00	0.00	0.00	0.00	0.00	8.03	18.81	145.09	120.38	46.64	46.93	85.96	127.08	63.80	18.68
ad. =	3.15	54.56	7.91	1.62	323	2.69	0.00	0.00	0.00	0.00	0.00	26.85	48.68	266.43	187.90	89.33	120.04	142.09	276.32	100.51	45.44
c.v. =	124.42	153.61	145.10	173.21	173.21	173.21	0.00	0.00	0.00	0.00	0.00	334.50	258.79	183.63	156.08	191.51	255.82	165.29	217.44	157.52	24328

* See Figs. 3, and 4 for transect locations.

Appendix 2. SYSTAT multiple regression analysis output for the complete season (5 June to 23 September 1977-1989) in the central Alaska Beaufort Sea.

```
>USE 'HD84:Applications:Statistics:SystatModules:863txt'
VARIABLES IN SYSTAT FILE ARE:

      DENS        DENSTRAN          YEAR             DRY             TIME
     DEPTH        DEPTRAN       WESTEAST         WESTRAN             DIST
   DISTRAN           WSPD           WDIR          ORDWND         ORDWTRAN
   NCOMWND        NECOMWND           ICE         ICETRAN           WAVEHT
   DAYTRAN        WSPDTRAN      WAVETRAN         HRBITRT             AREA
>CATEGORY HABITAT=5
>CATEGORY AREA=2
>MODEL DENSTRAN=CONSTANT+YEAR+DAY+DAYTRAN+TIME+WESTEAST+WSPD+WDIR+WSPD*WDIR+,
>ICETRAN+WAVETRAN+HABITAT+AREA+YEAR*AREA+HABITAT*DAYTRAN+HABITAT*TIME+,
>HABITAT*WSPD+HABITAT*WDIR+HABITAT*WAVETRAN+HABITAT*ICETRAN
>PRINT LONG
>ESTIMATE
>
```

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YOU ARE IN MGLH MODULE

DEP VAR: DENSTRAN N: 474 MULTIPLE R: .758 SQUARED MULTIPLE R: .574

ESTIMATES OF EFFECTS $B = (X'X)^{-1}X'Y$

		DENSTRAN
CONSTANT		-2.179
YEAR		-0.038
DAY		0.097
DAYTRAN		-0.001
TIME		0.001
WESTEAST		-0.054
WSPD		0.003
WDIR		-0.003
WSPD WDIR		0.000
ICETRAN		-0.047
WAVETRAN		-0.376
HABITAT	1	-0.229
HABITAT	2	3.911
HABITAT	3	-4.105
HABITAT	4	1.513
AREA	1	-0.010
YEAR AREA	1	0.016
HABITAT DAYTRAN	1	-0.000
HABITAT DAYTRAN	2	0.000
HABITAT DAYTRAN	3	0.000
HABITAT DAYTRAN	4	0.000
HABITAT TIME	1	0.002
HABITAT TIME	2	-0.003
HABITAT TIME	3	0,002

HABITAT 4
TIME -0.002

HABITAT 1
USPD 0.004

HABITAT 2
WSPD -0.006

HABITAT 3
WSPD 0.062

HABITAT 4
WSPD -0.044

HABITAT 1
WDIR 0.001

HABITAT 2
WDIR 0.000

HABITAT 3
WDIR -0.002

HABITAT 4
WDIR 0.004

HABITAT 1
WAVETRAN 0.227

HABITAT 2
WAVETRAN 0.329

HABITAT 3
WAVETRAN -0.754

HABITAT 4
WAVETRAN 0.080

HABITAT 1
ICETRAN -0.357

HABITAT 2
ICETRAN 0.001

HABITAT 3
ICETRAN -0.051

HABITAT 4
ICETRAN 0.119

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
YEAR	3.632	1	3.632	1.296	0.256
DAY	55.005	1	55.006	19.622	0.000
DAYTRAN	0.412	1	0.412	0.147	0.702
TIME	2.849	1	2.849	1.016	0.314
WESTEAST	1,442	1	1.442	0.515	0.474
WSPD	0.005	1	0,005	0.002	0.965
WDIR	2,330	1	2.330	0.831	0.362
WSPD*					
[illegible]	[illegible]		[illegible]	[illegible]	

ICETRAN	0.298	1	0.298	0.106	0.745
WAVETRAN	19.075	1	19.075	6.805	0.009
HABITAT	47.270	4	11.818	4.216	0.002
AREA	0.000	1	0.000	0.000	0.989
YEAR* AREA	0.328	1	0.328	0.117	0.732
HABITAT* DAYTRAN	26.627	4	6.657	2.375	0.051
HABITAT* TIME	152.752	4	38.188	13.623	0.000
HABITAT* WSPD	22.485	4	5.621	2.005	0.093
HABITAT* WDIR	10.221	4	2.555	0.912	0.457
HABITAT* WAVETRAN	26.491	4	6.623	2.362	0.052
HABITAT* ICETRAN	25.971	4	6.493	2.316	0.057
ERROR	1213.824	433	2.803		

Appendix 3. SYSTAT multiple regression analysis output for molt period only (15 July to 15 August 1977-1989) in the central Alaska Beaufort Sea.

```
>USE 'HD84:Applications:Statistics:Systat Modules:moltxt'
VARIABLES IN SYSTAT FILE ARE:

     DENS      DENSTRAN       YEAR        DAY       TIME
    DEPTH      DEPTRAN    WESTEAST    WESTRAN       DIST
  DISTRAN         WSPD        WDIR     ORDWND   ORDWTRAN
  NCOMWND      NECOMWND        ICE    ICETRAN     WAVEHT
  DAYTRAN      WSPDTRAN   WAVETRAN    HABITAT       AREA
>CATEGORY HABITAT=5
>CATEGORY AREA=2
>MODEL DENSTRAN=CONSTANT+YEAR+DAY+DAYTRAN+TIME+WESTEAST+WSPD+WDIR+WSPD*WDIR+,
>ICETRAN+WAVETRAN+HABITAT+AREA+YEAR*AREA+HABITAT*DAYTRAN+HABITAT*TIME+,
>HABITAT*WSPD+HABITAT*WDIR+HABITAT*WAVETRAN+HABITAT*ICETRAN
>PRINT LONG
>ESTIMATE
>
```

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YOU ARE IN MGLH MODULE

DEP VAR:DENSTRAN N: 275 MULTIPLE R: .825 SQUARED MULTIPLE R: .681

ESTIMATES OF EFFECTS $B = (X'X)^{-1} X'Y$

		DENSTRAN
CONSTANT		-1.269
YEAR		-0.076
DRY		0.099
DAYTRAN		-0.001
TIME		0.001
WESTEAST		-0.128
WSPD		-0.025
WDIR		-0.007
WSPD WDIR		0.000
ICETRAN		0.374
WAVETRAN		-0.457
HABITAT	1	-1.645
HABITAT	2	3.244
HABITAT	3	2.415
HABITAT	4	3.258
AREA	1	-1.121
YEAR AREA	1	0.153
HABITAT DAYTRAN	1	0.000
HABITAT DAYTRAN	2	0.000
HABITAT DAYTRAN	3	-0.000
HABITAT DAYTRAN	4	-0.001
HABITAT TIME	1	0.002
HABITAT TIME	2	-0.003
HABITAT TIME	3	0.001

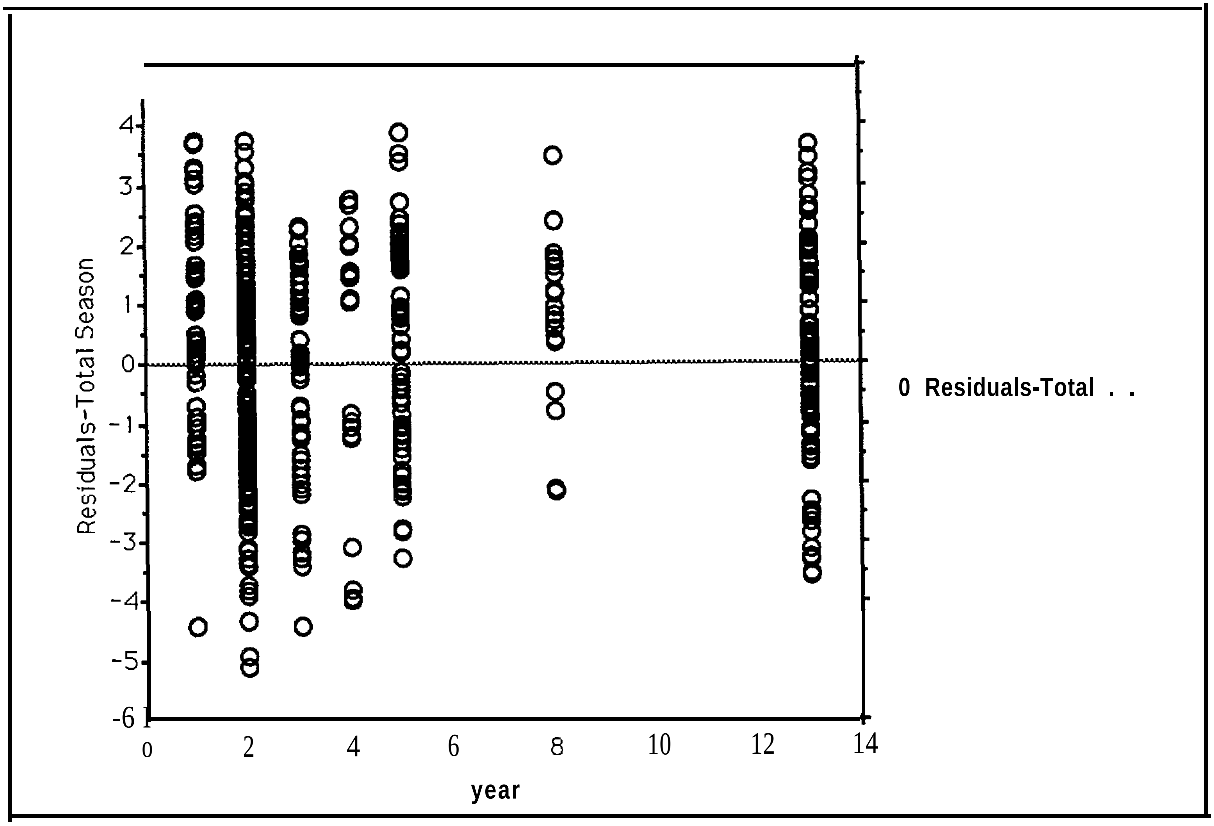
HABITAT	4	
TIME		-0.000
HABITAT	1	
WSPD		0.003
HABITAT	2	
WSPD		0.004
HABITAT	3	
USPD		0.034
HABITAT	4	
USPD		-0.077
HABITAT	1	
WDIR		0.003
HABITAT	2	
WDIR		0.003
HABITAT	3	
WDIR		-0.002
HABITAT	4	
WDIR		0.000
HABITAT	1	
WAVETRAN		0.359
HABITAT	2	
WAVETRAN		0.198
HABITAT	3	
WAVETRAN		-1.030
HABITAT	4	
WAVETRAN		0.210
HABITAT	1	
ICETRAN		-0.322
HABITAT	2	
ICETRAN		1.181
HABITAT	3	
ICETRAN		0.195
HABITAT	4	
ICETRAN		-0.892

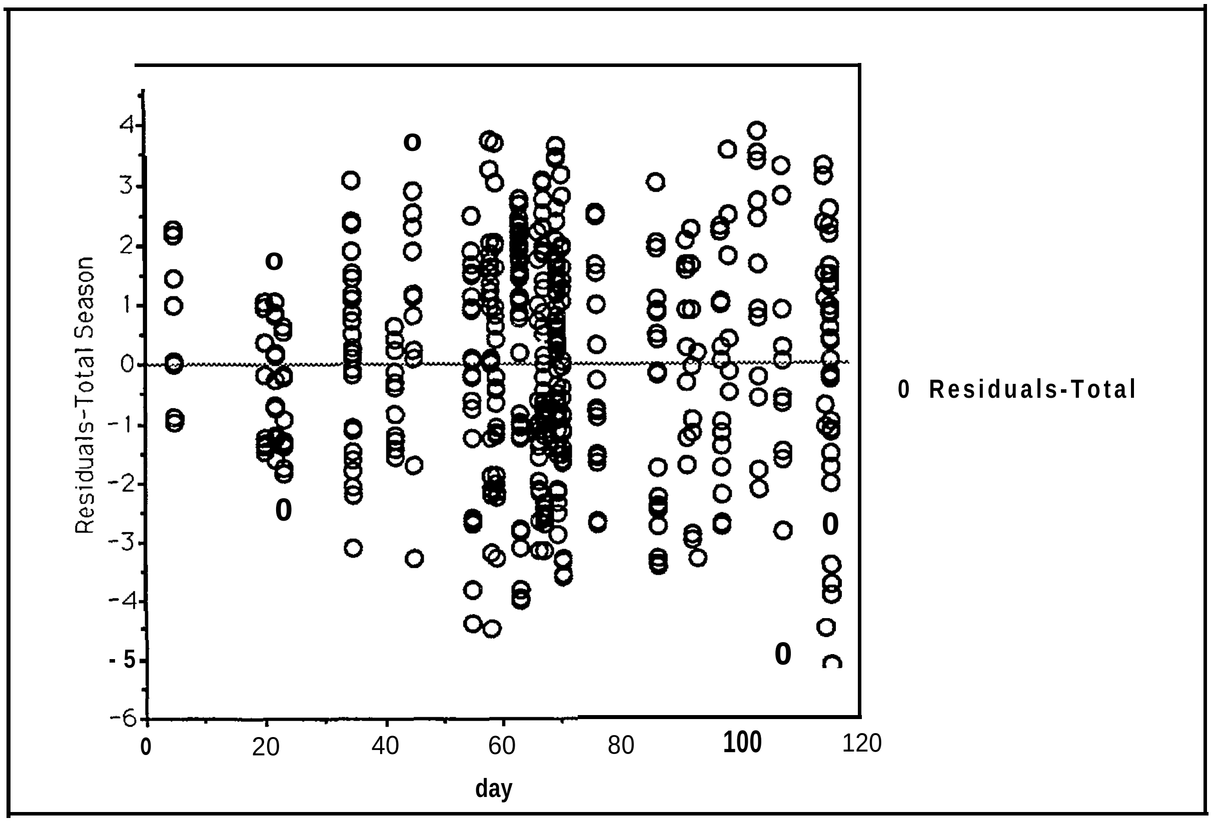
ANALYSIS OF VARIANCE

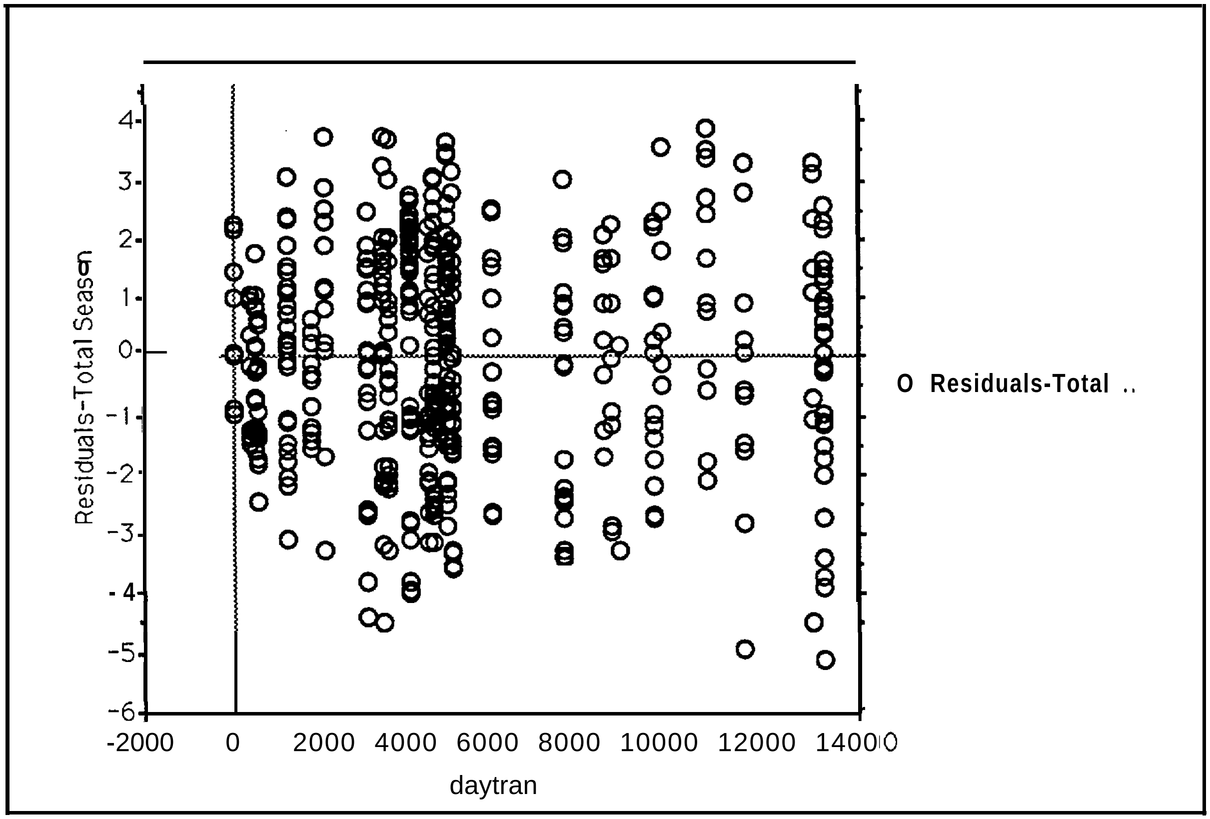
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
YEAR	8.389	1	8.389	3.303	0.070
DAY	0.438	1	0.438	0.172	0.678
DAYTRAN	0.209	1	0.209	0.082	0.774
TIME	3.410	1	3.410	1.343	0.248
WESTEAST	4.807	f	4.807	1.893	0.170
USPD	0.434	1	0.434	0.171	0.680
WDIR	7.266	1	7.266	2.861	0.092
WSPD* WDIR	18.892	1	18.892	7.439	0.007

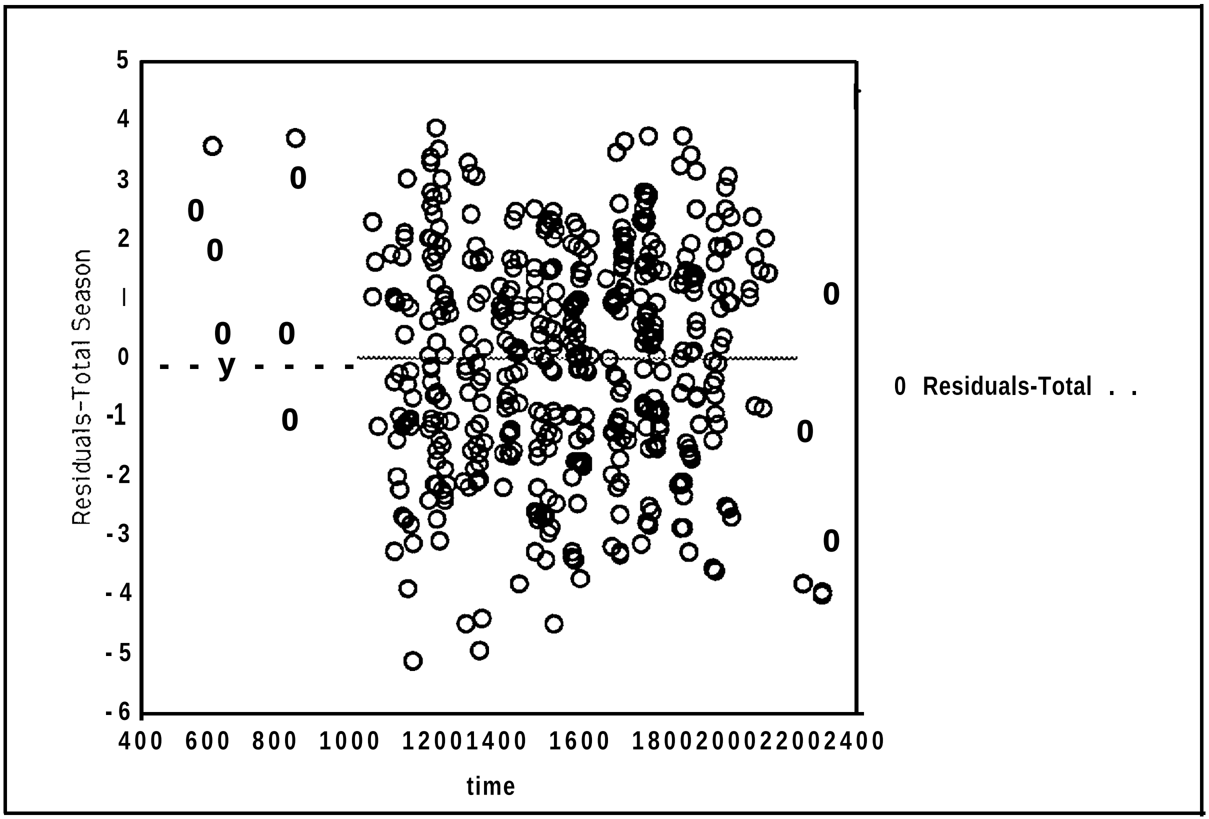
1CETRAN	3.844	1	3.844	1.514	0.220
WAVETRAN	16.841	1	16.841	6.632	0.011
HABITRT	16.045	4	4.011	1.580	0.180
AREA	3,511	1	3.511	1.383	0.241
YEAR* AREA	18.685	1	18.685	7.358	0.007
HABITAT* DAYTRAN	12.228	4	3.057	1.204	0.310
HABITAT* TIME	74.523	4	18.631	7.336	0.000
HABITAT* WSPD	14.635	4	3.659	1.441	0.221
HABITAT* WDIR	6,766	4	1.692	0.666	0.616
HABITAT* WAVETRAN	11.790	4	2.947	1.161	0.329
HABITAT* ICETRAN	37.145	4	9.286	3.657	0.007
ERROR	594.237	234	2.539		

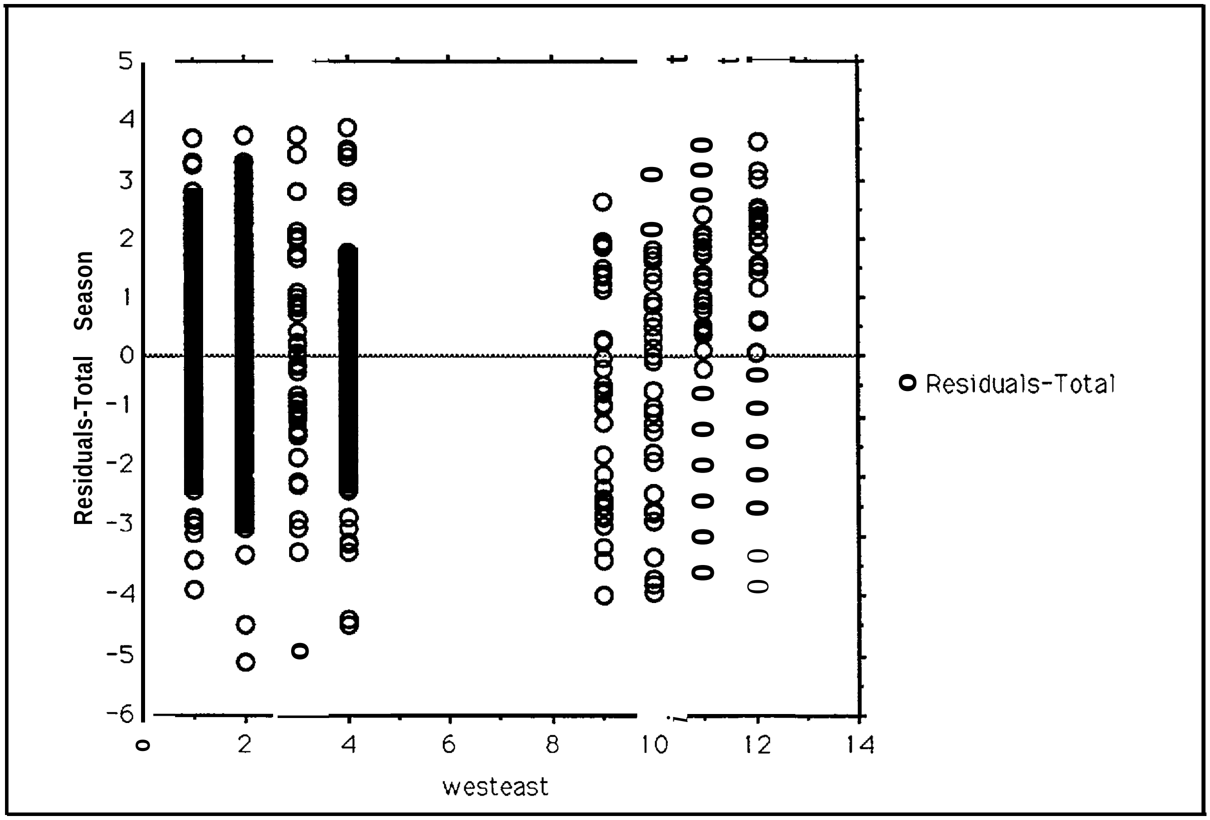
Appendix 4. Plots of multiple regression residuals vs. the various independent variables used in the complete season (5 June to 23 September 1977-1989) and the molt period (15 July to 15 August 1977-1989) multiple regression analyses.

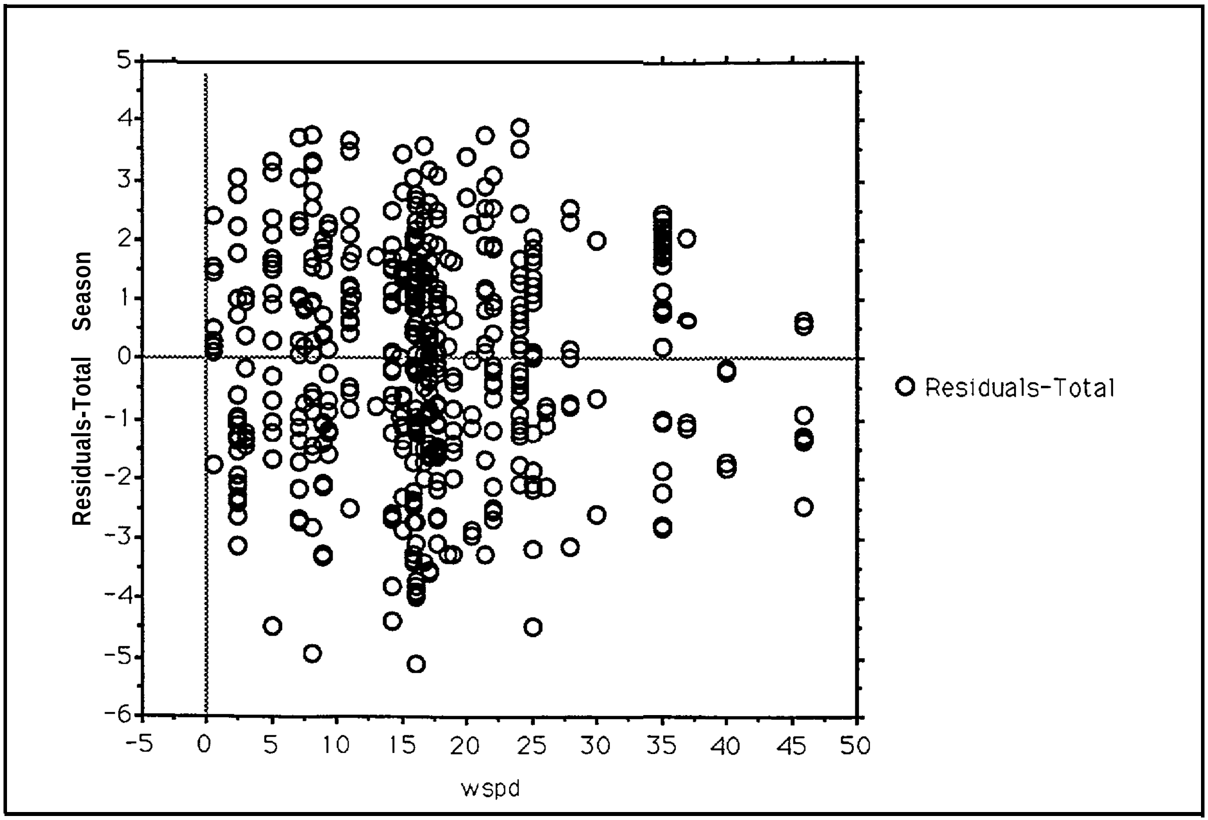

Residuals-Total Season
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
2
4
6
8
10
12
14
year
0 Residuals-Total . .

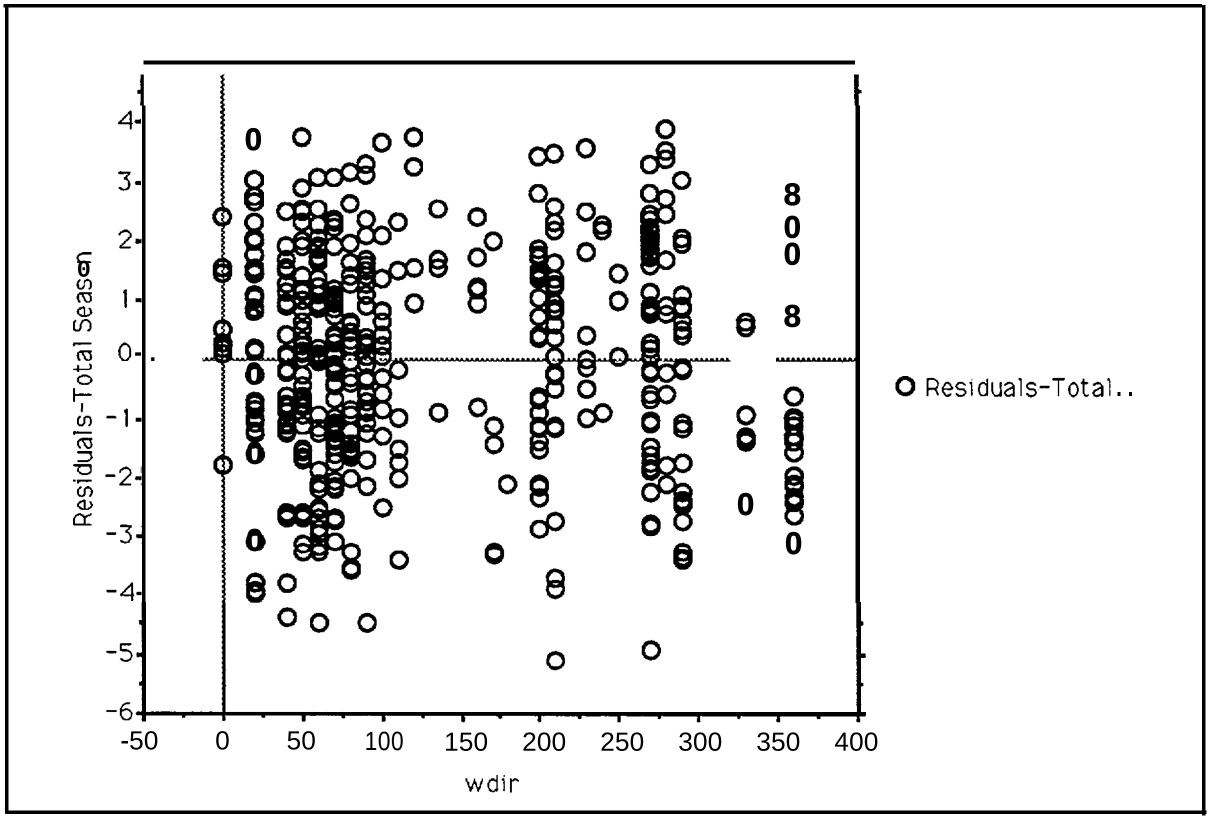

Residuals-Total Season
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
20
40
60
80
100
120
day
0 Residuals-Total

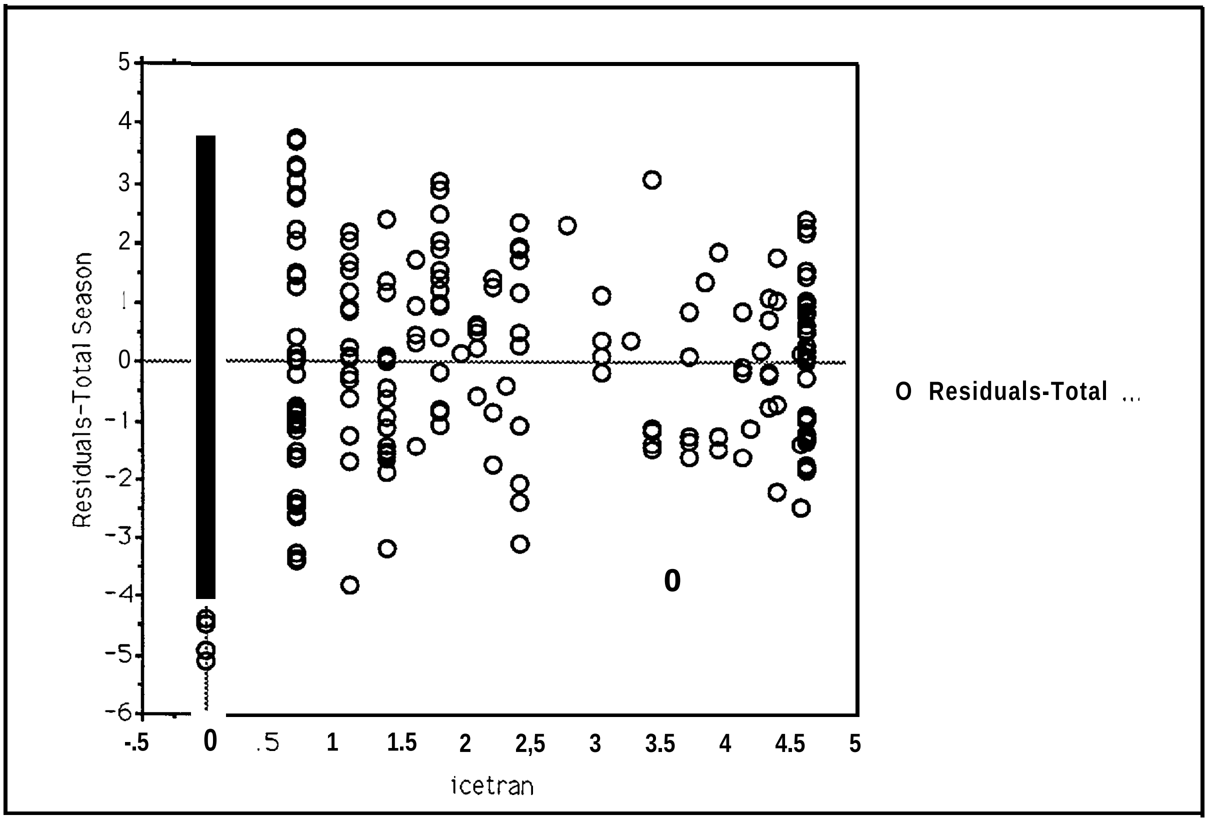

Residuals-Total Season
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-2000
0
2000
4000
6000
8000
10000
12000
14000
daytran
O Residuals-Total ..

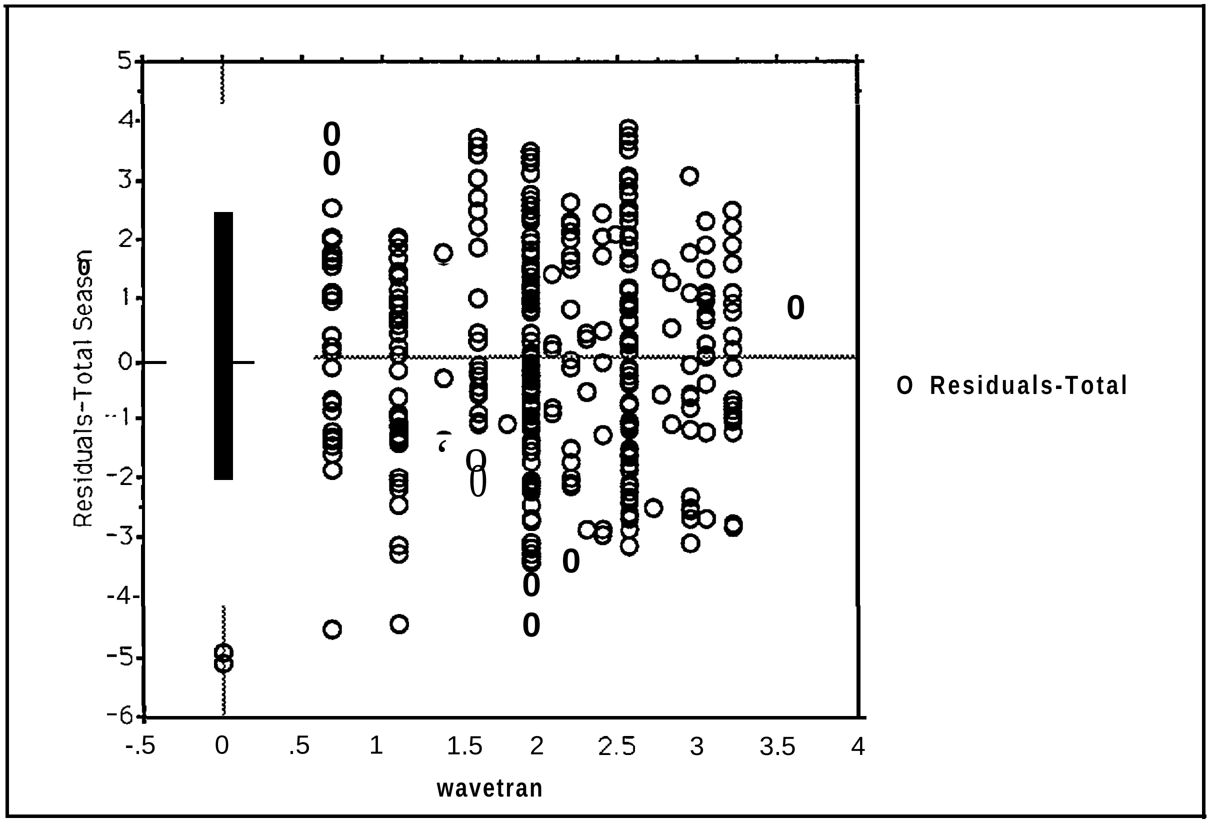

Residuals-Total Season
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
time
0 Residuals-Total . .


Residuals-Total Season
westeast
Residuals-Total

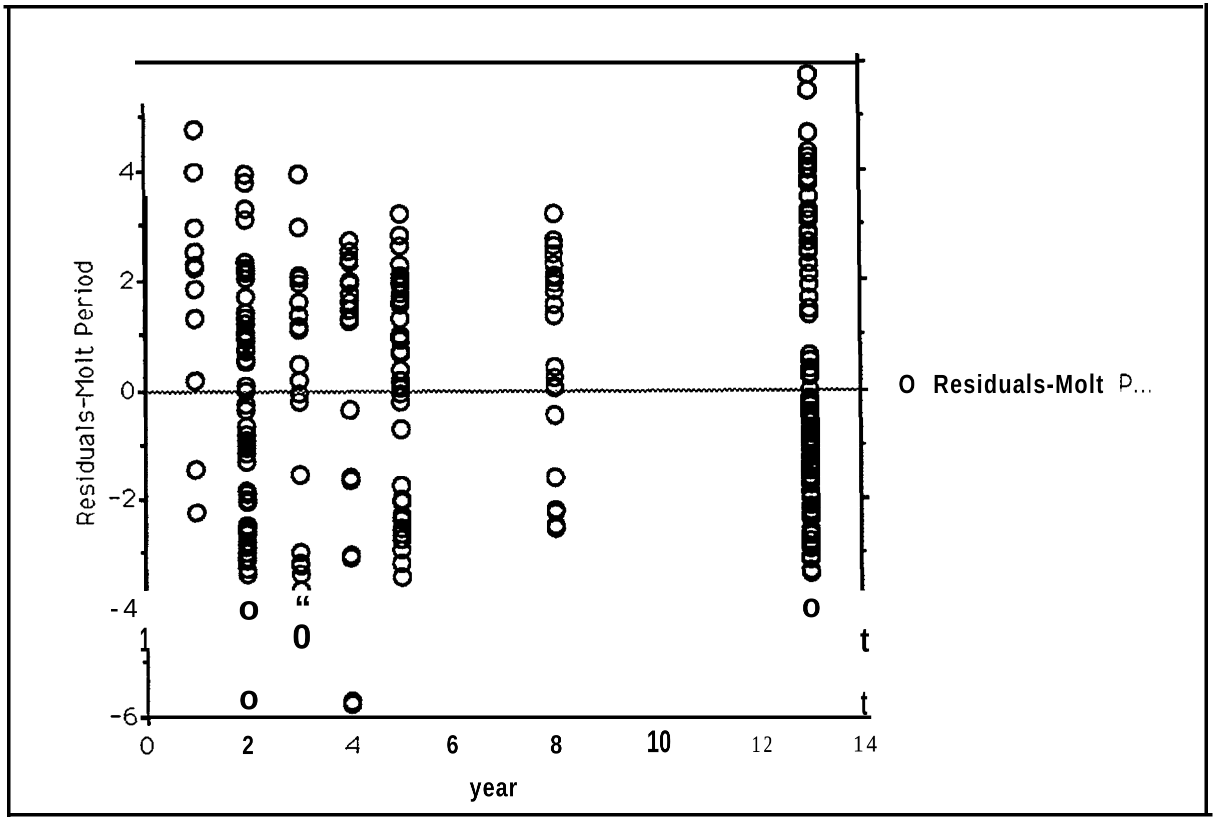

Residuals-Total Season
wspd
Residuals-Total

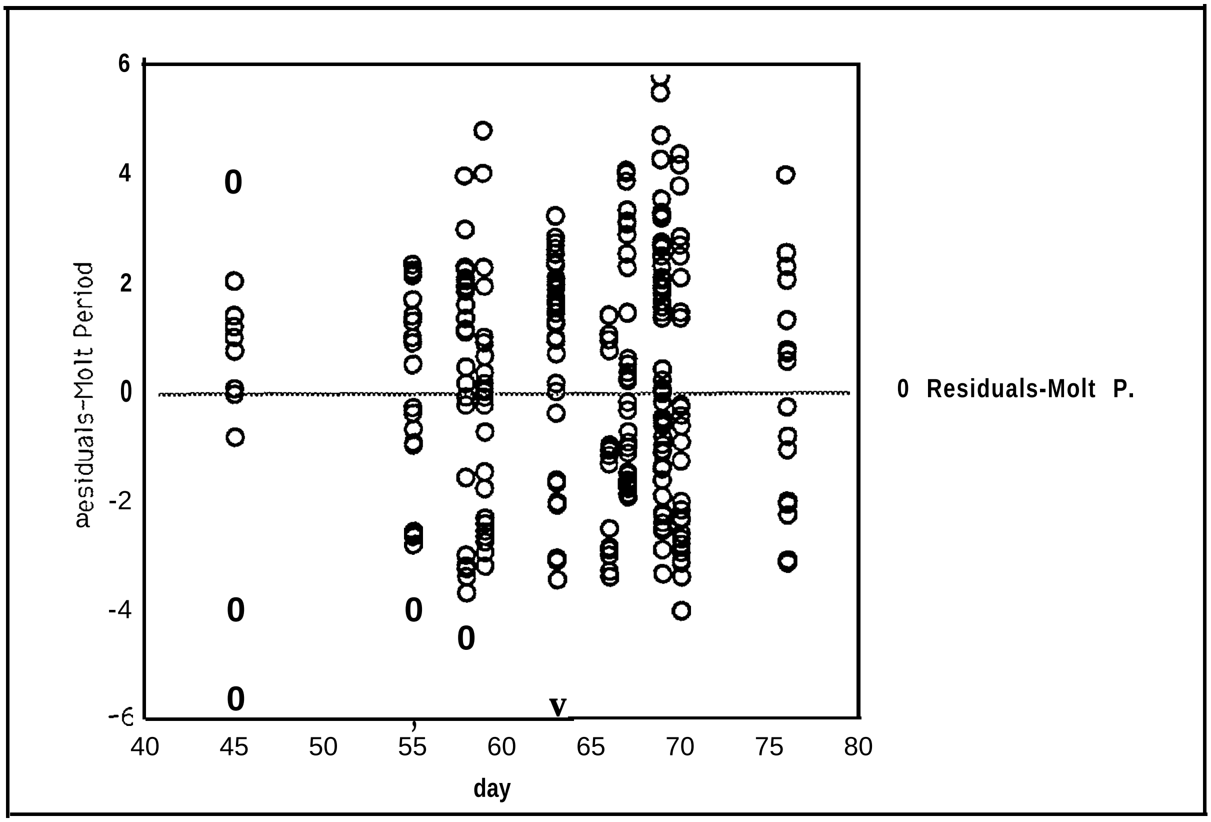

Residuals-Total Season
wdir
Residuals-Total..

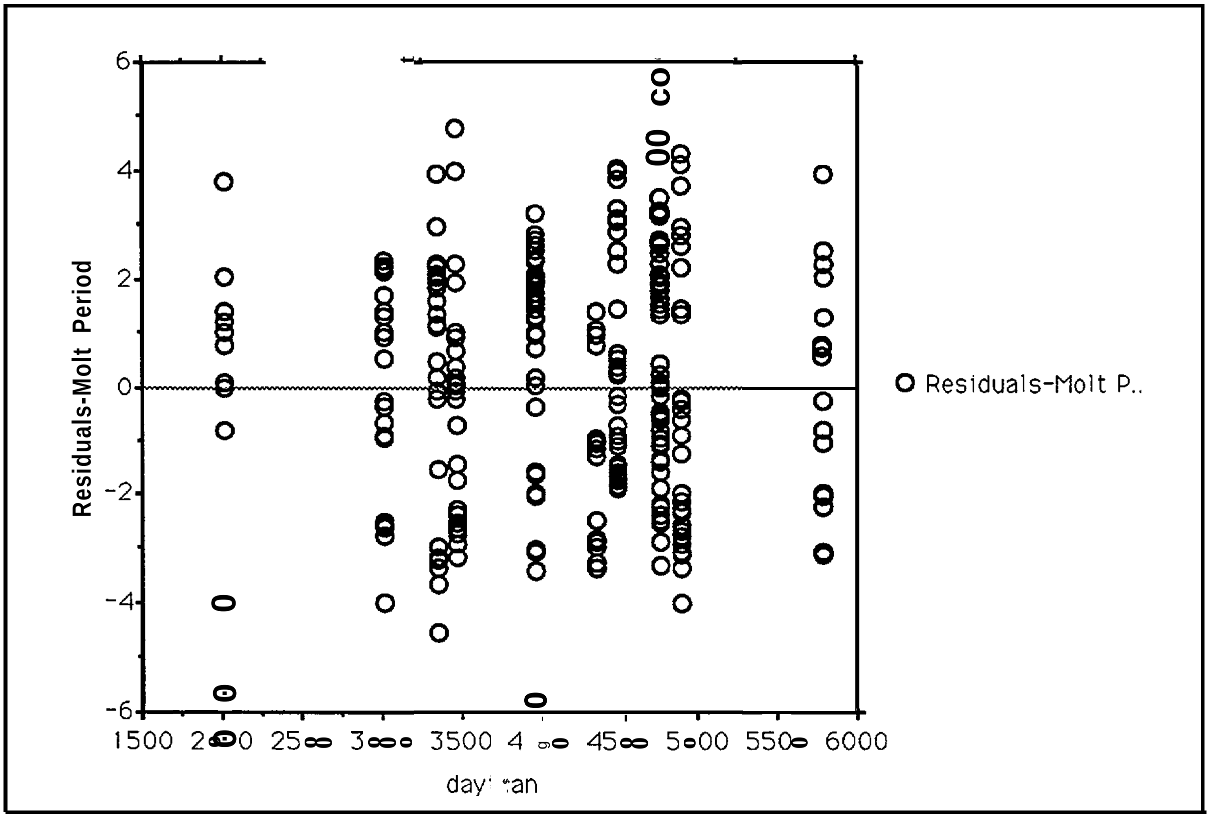

Residuals-Total Season
icetran
Residuals-Total ...

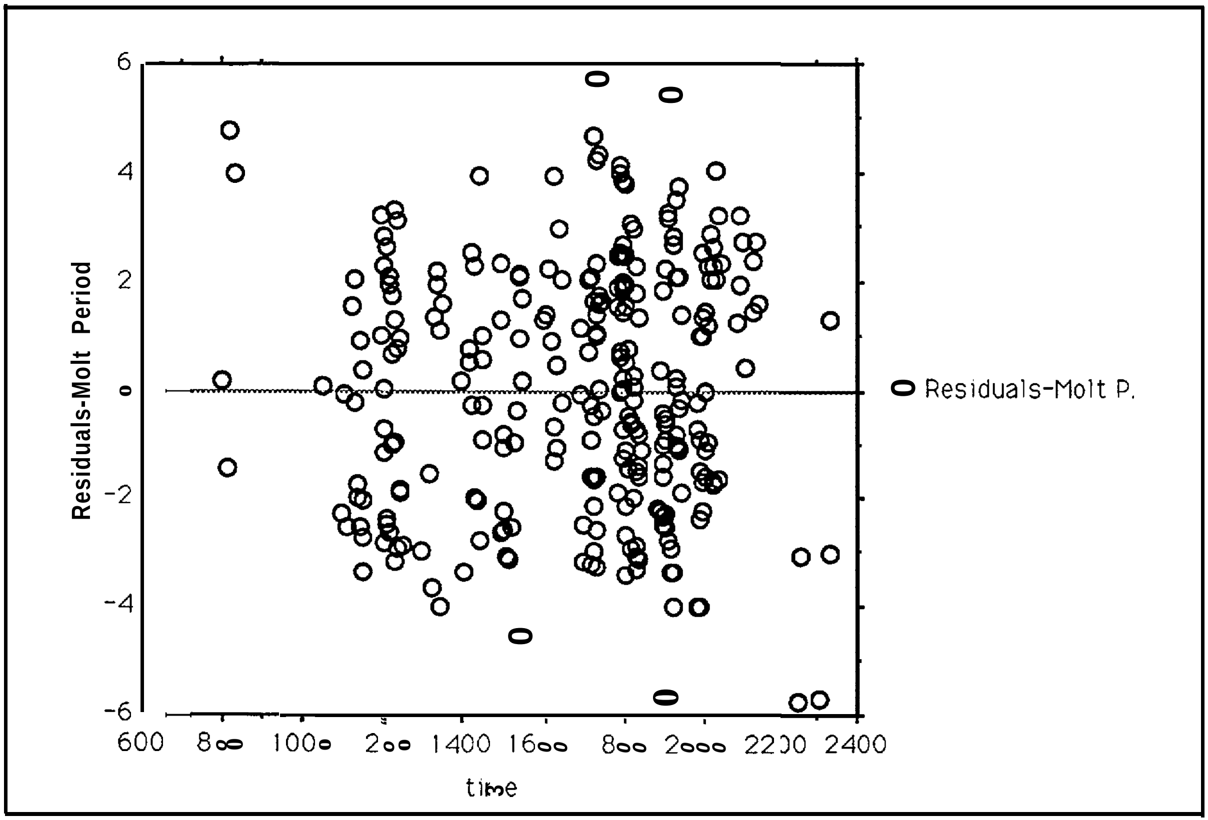


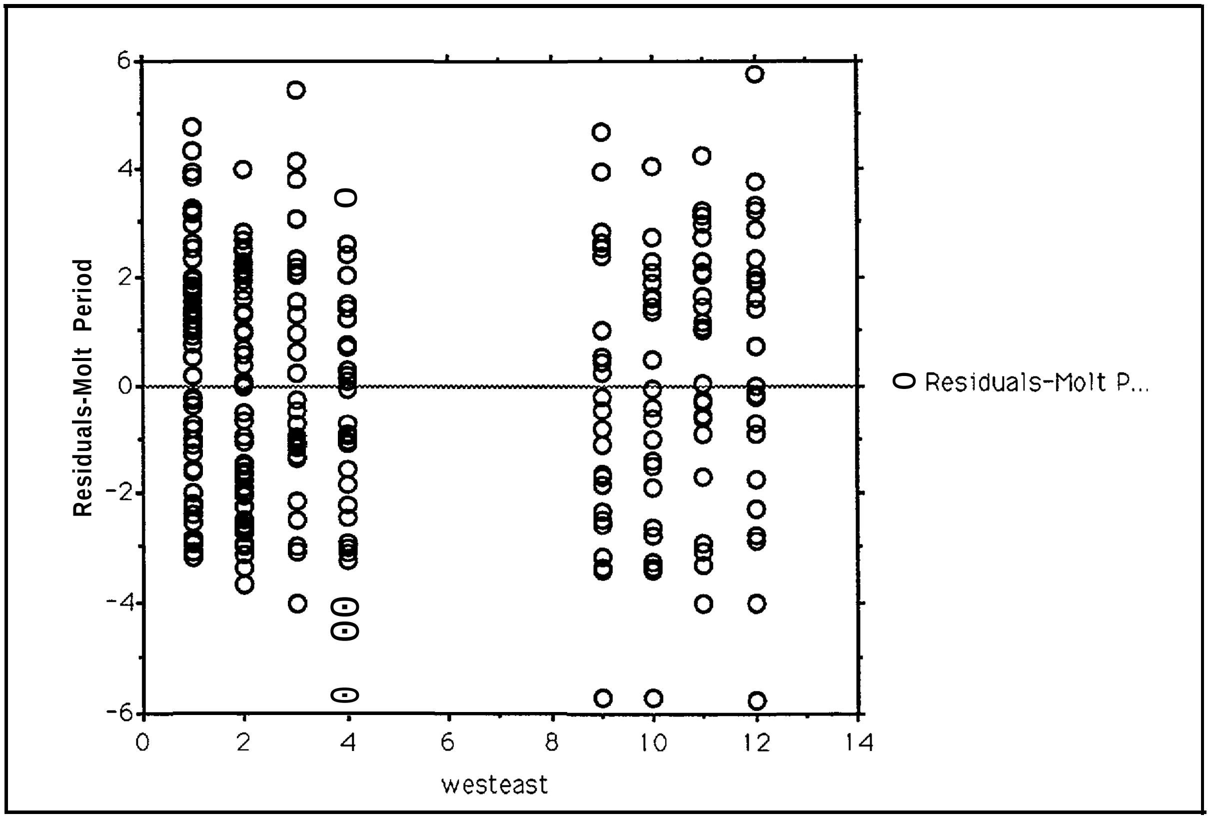
Residuals-Total Season
wavetran
-.5
0
.5
1
1.5
2
2.5
3
3.5
4
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
O Residuals-Total

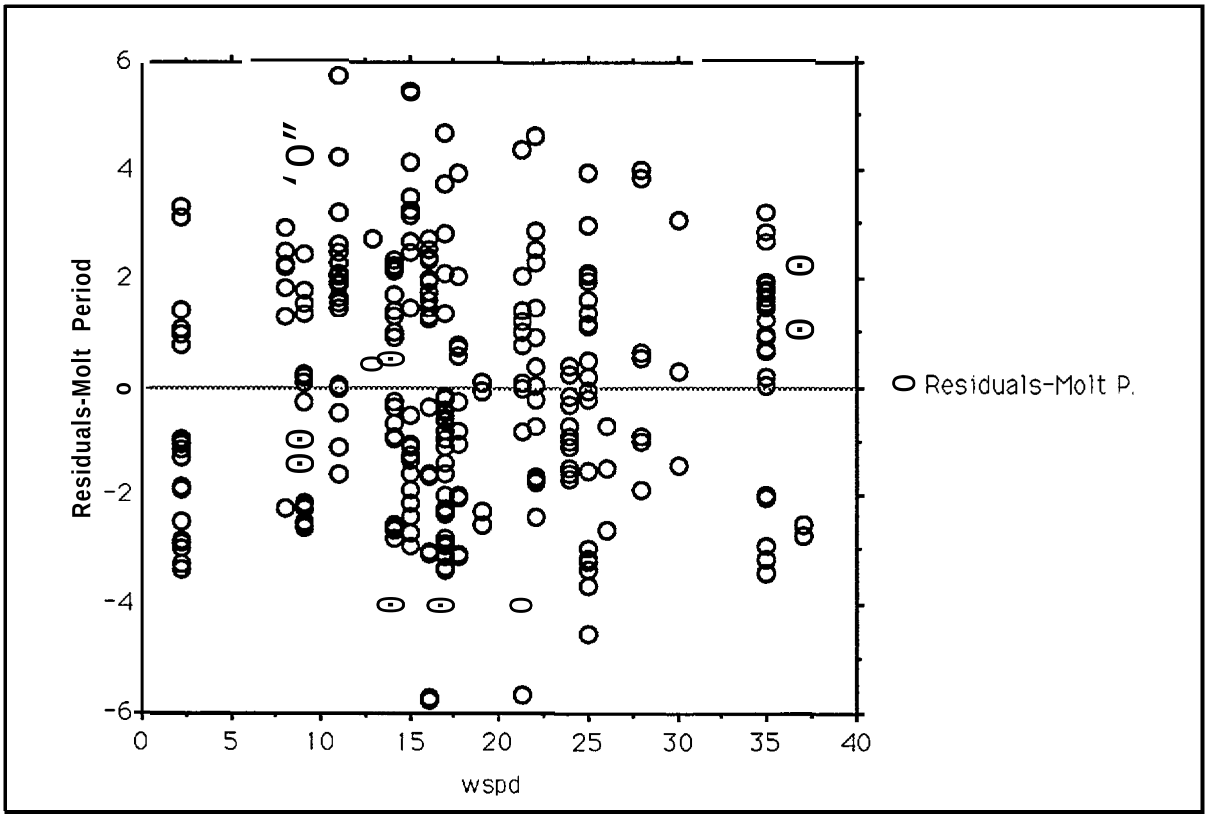

Residuals-Molt Period
year
0 2 4 6 8 10 12 14
-6 -4 -2 0 2 4
O Residuals-Molt P...

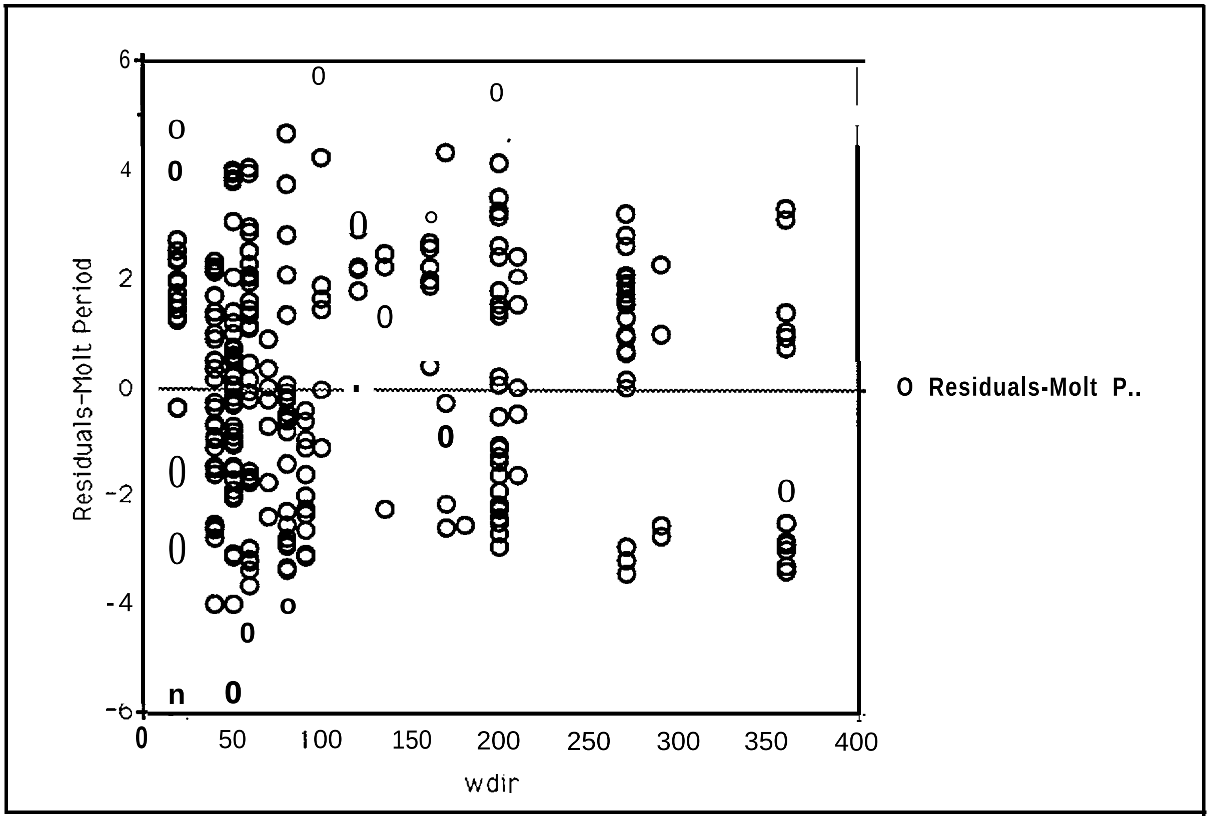

Residuals-Molt Period
day
40 45 50 55 60 65 70 75 80
-6 -4 -2 0 2 4 6
0 Residuals-Molt P.

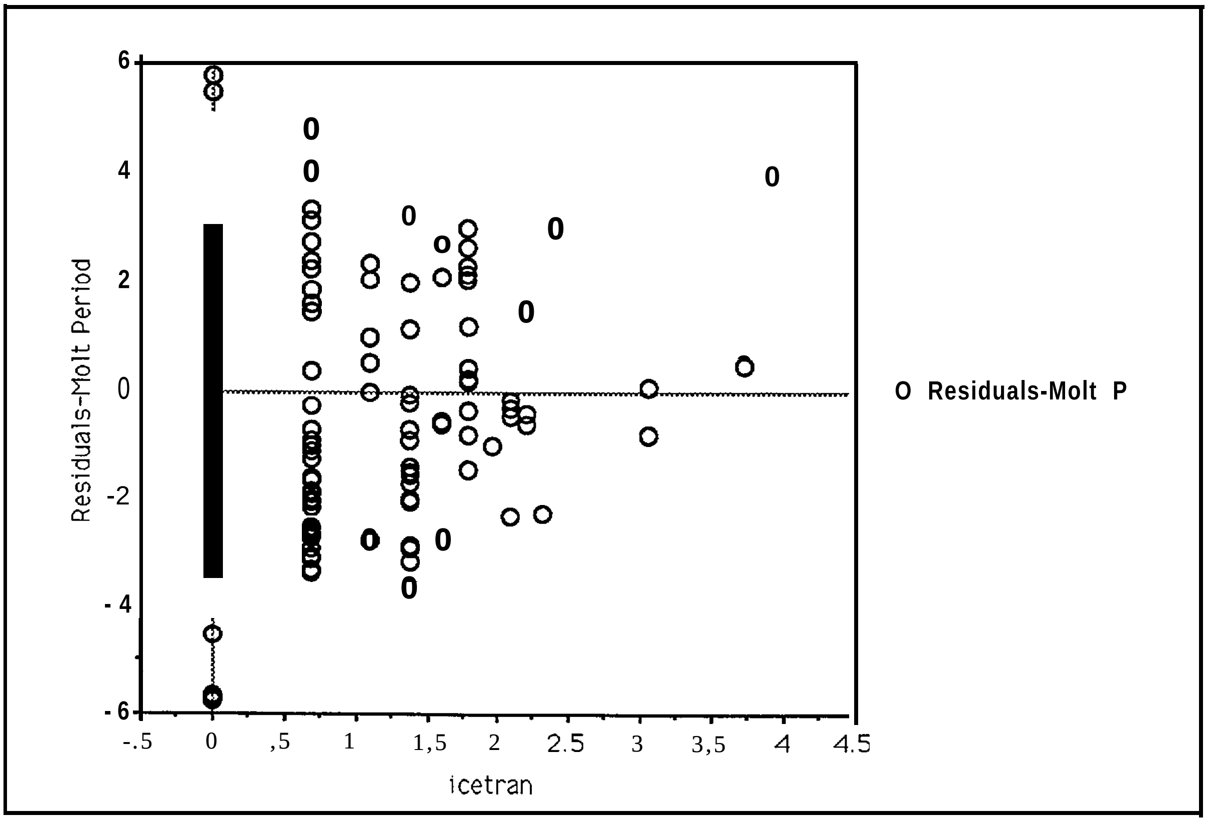

Residuals-Molt Period
6
4
2
0
-2
-4
-6
1500
3500
6000
Residuals-Molt P..

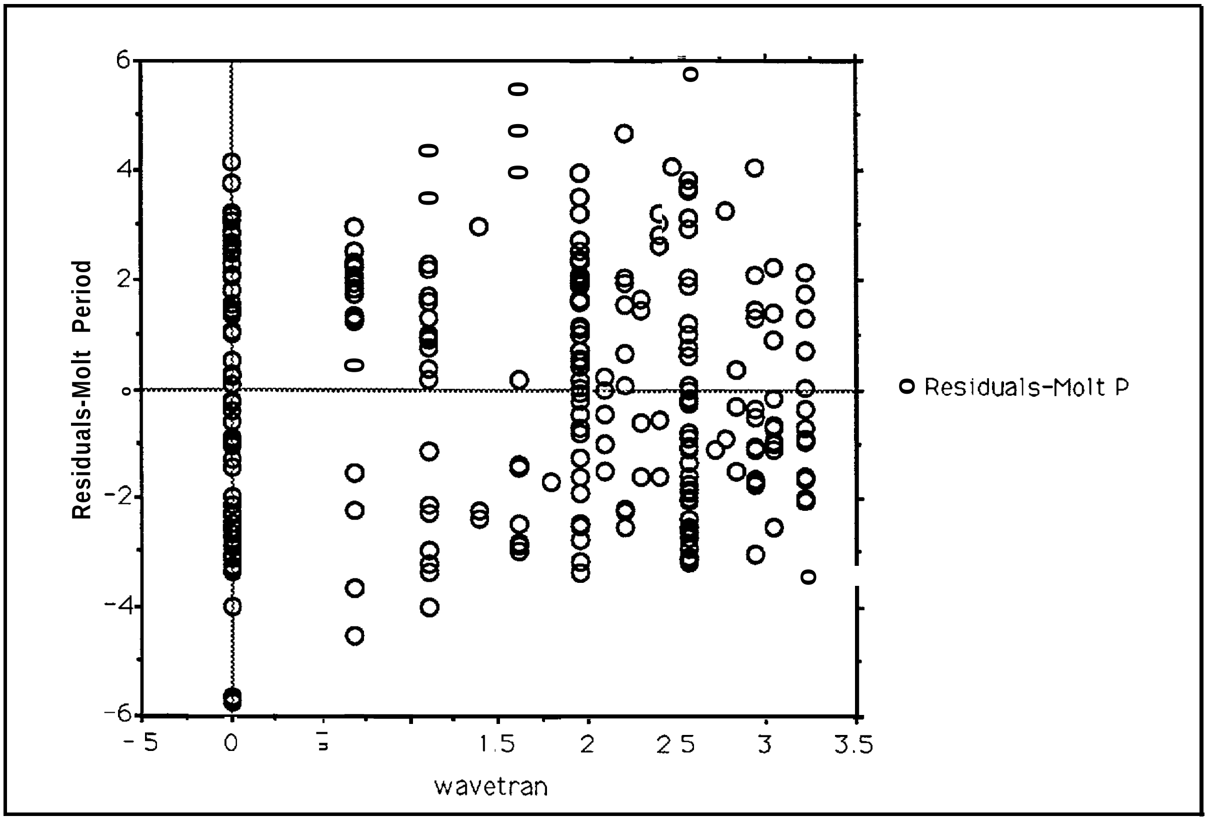

Residuals-Molt Period
6
4
2
-2
-4
-6
600
1400
2400
Residuals-Molt P.


Residuals-Molt Period
6
4
2
0
-2
-4
-6
0
2
4
6
8
10
12
14
westeast
Residuals-Molt P...

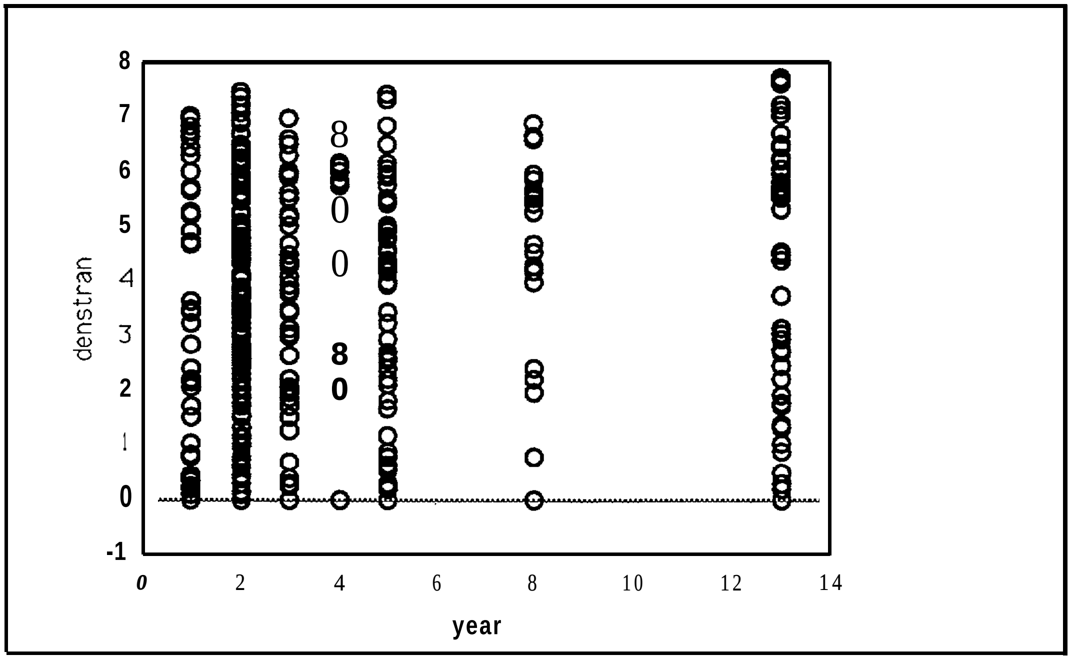

Residuals-Molt Period
6
4
2
0
-2
-4
-6
0
5
10
15
20
25
30
35
40
wspd
Residuals-Molt P.


Residuals-Molt Period
wdir
0
50
100
150
200
250
300
350
400
6
4
2
0
-2
-4
-6
O Residuals-Molt P..

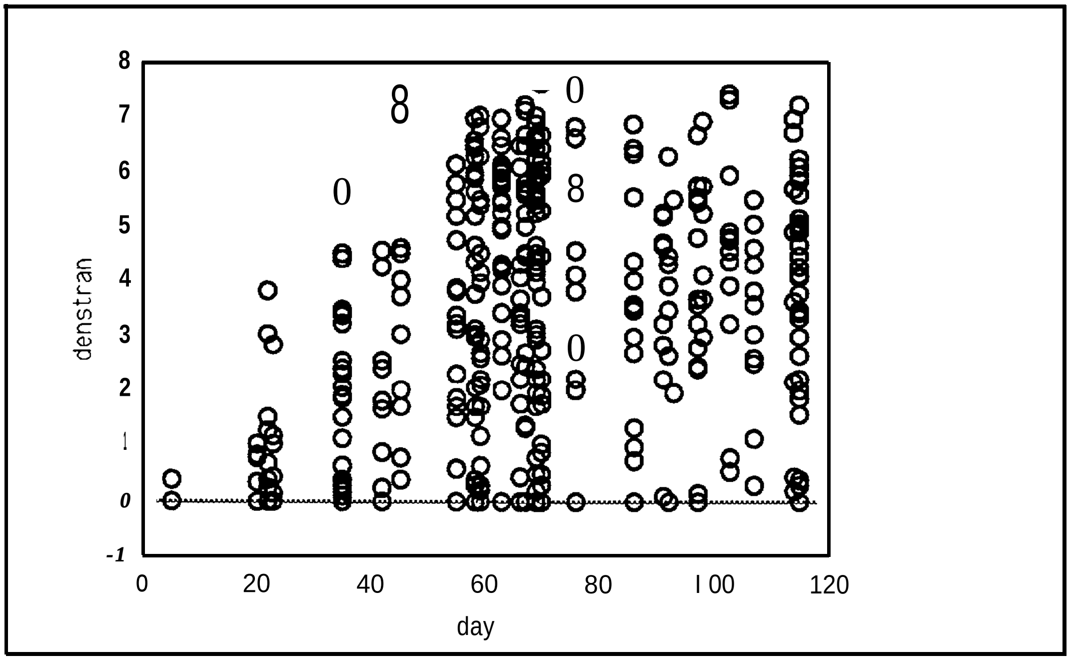

Residuals-Molt Period
icetran
-.5
0
,5
1
1,5
2
2.5
3
3,5
4
4.5
6
4
2
0
-2
-4
-6
O Residuals-Molt P

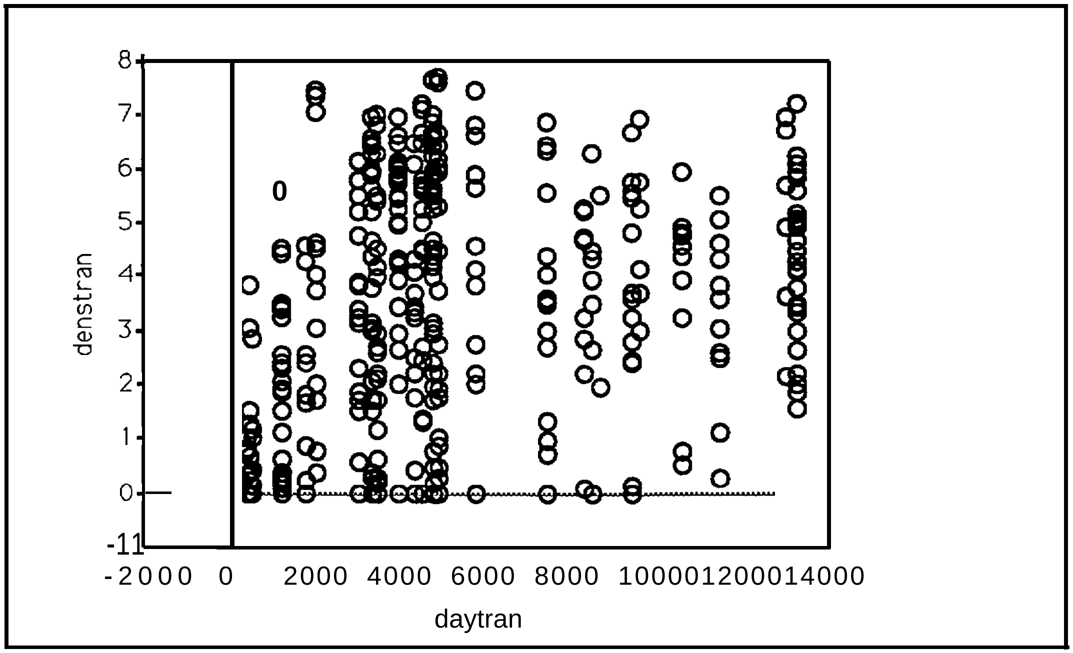

Residuals-Molt Period
6
4
2
0
-2
-4
-6
-.5
0
1.5
2
2.5
3
3.5
wavetran
Residuals-Molt P

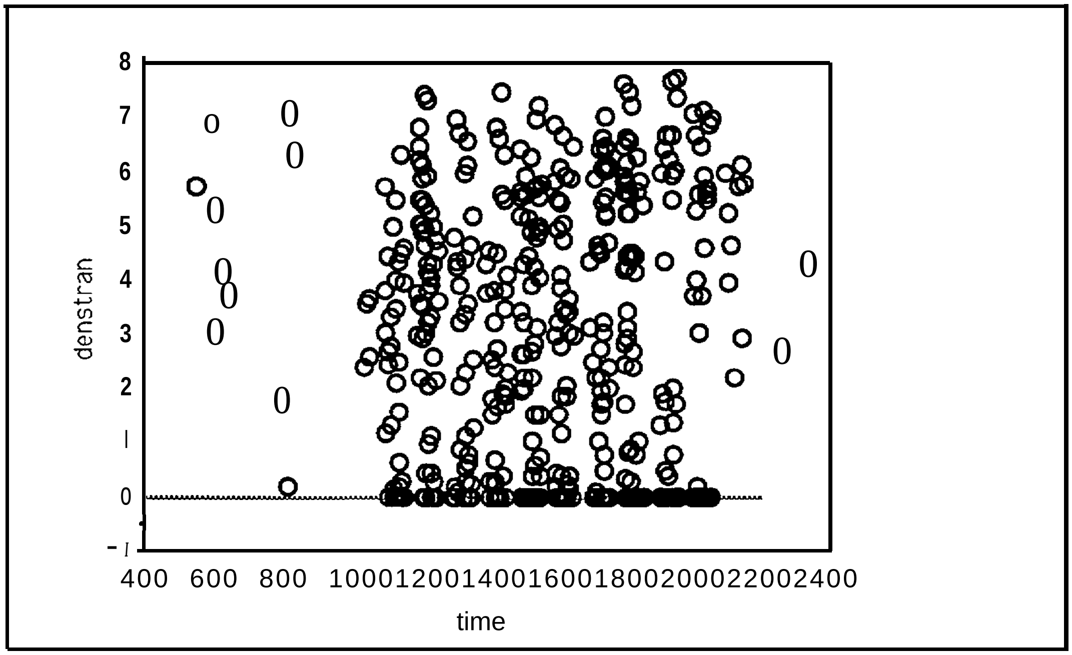
Appendix 5. Plots of transformed oldsquaw density (ln (density + 1)) vs. the various independent variables used in the complete season (5 June to 23 September 1977-1989) and the molt period (15 July to 15 August 1977-1989) multiple regression analyses.

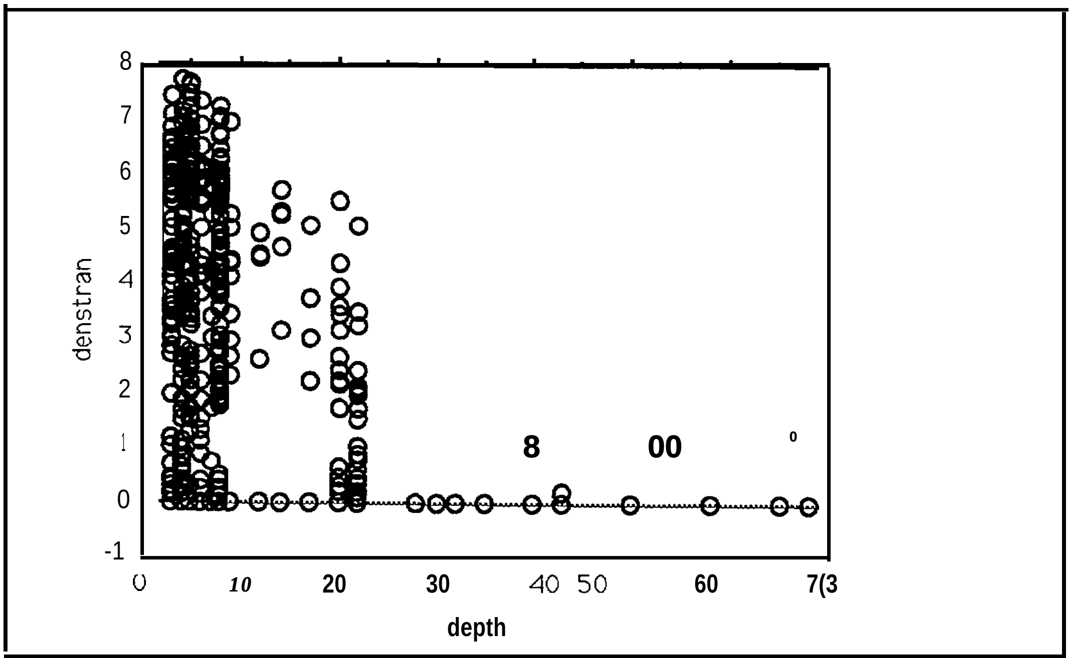


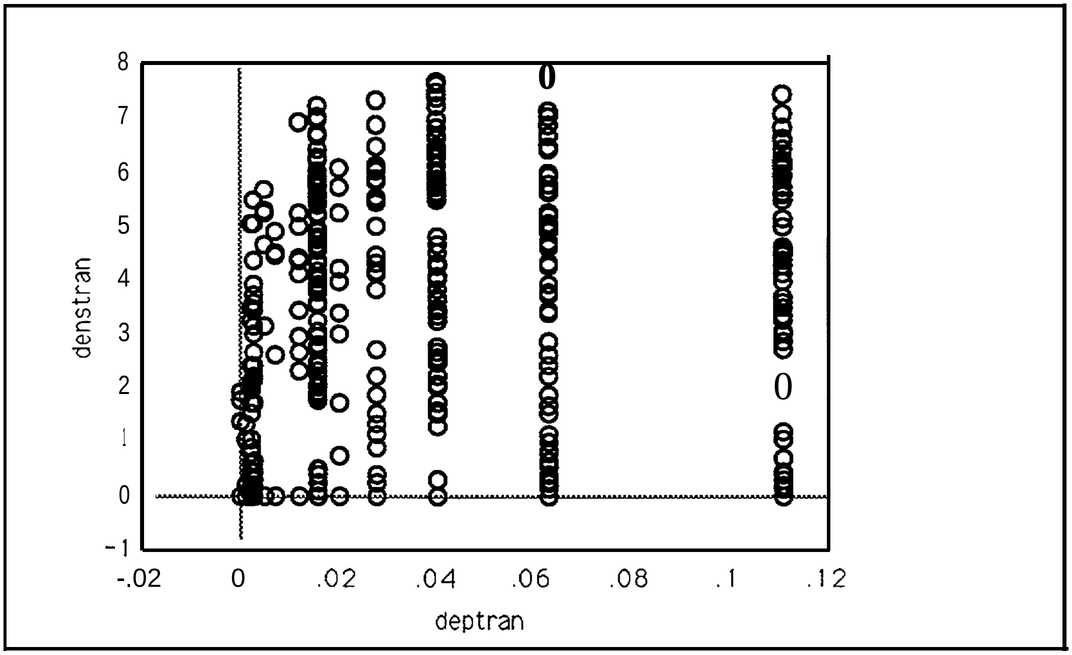
8
7
6
5
4
3
2
1
0
-1
denstran
0
2
4
6
8
10
12
14
year


8
7
6
5
4
3
2
1
0
-1
denstran
0
20
40
60
80
100
120
day

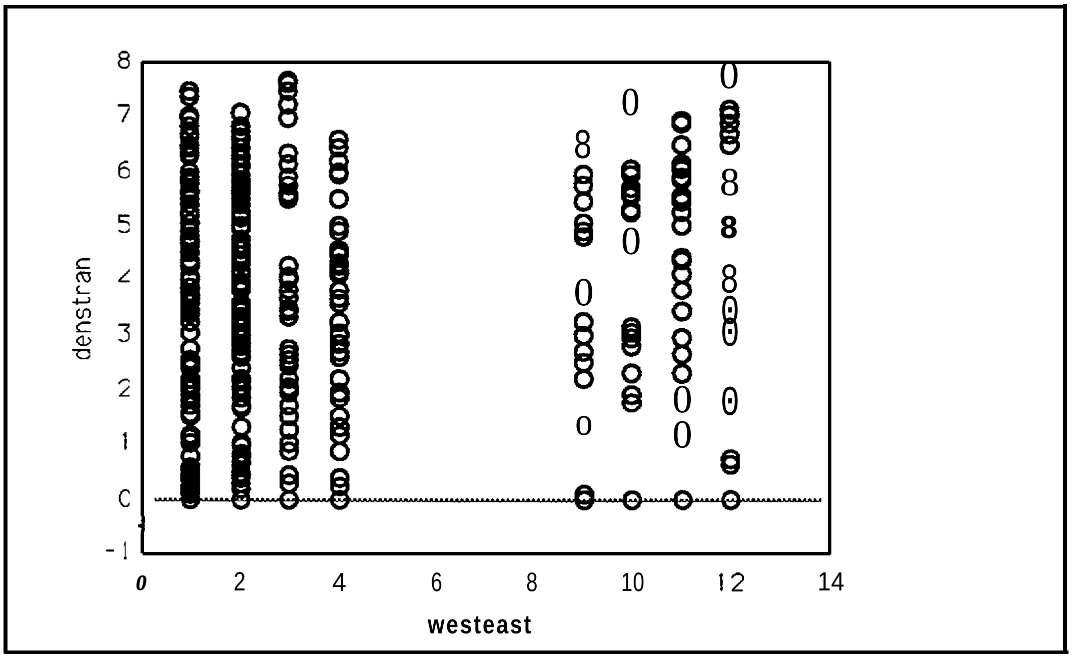

8
7
6
5
4
3
2
1
0
-11
0
denstran
-2000 0 2000 4000 6000 8000 10000 12000 14000
daytran

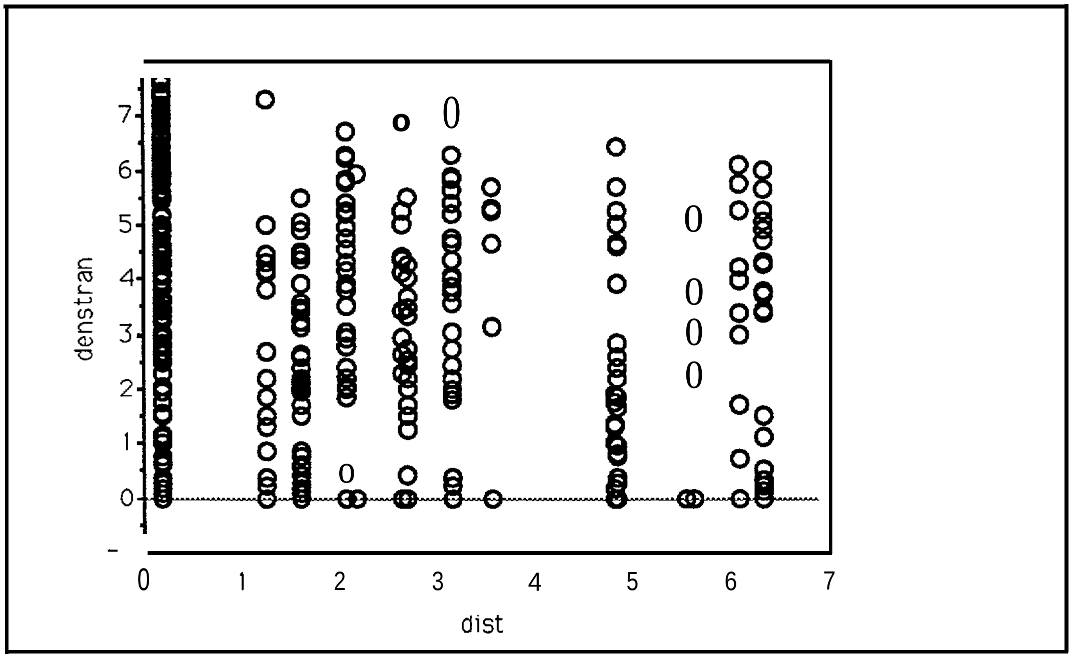

8
7
6
5
4
3
2
1
0
-1
denstran
400 600 800 1000 1200 1400 1600 1800 2000 2200 2400
time


8
7
6
5
4
3
2
1
0
-1
denstran
0
10
20
30
40 50
60
7(3
depth
8
00
0



8
7
6
5
4
3
2
1
0
-1
denstran
-.02
0
.02
.04
.06
.08
.1
.12
deptran


denstran
westeast
8
7
6
5
4
3
2
1
0
-1
0
2
4
6
8
10
12
14


denstran
dist
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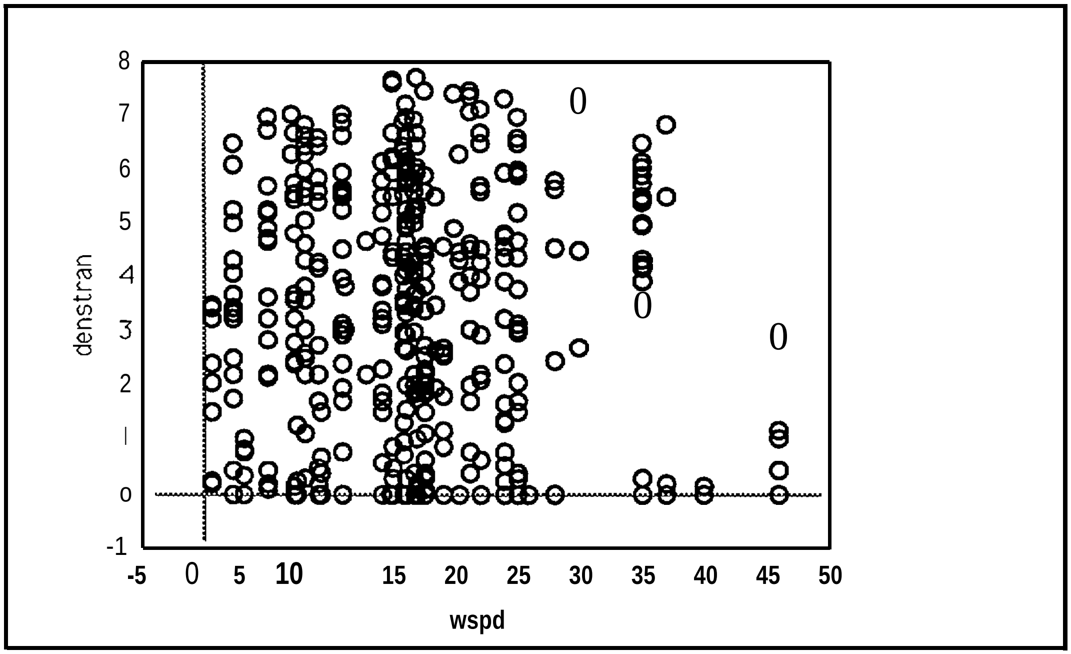
6
7



8
7
6
5
4
3
2
1
0
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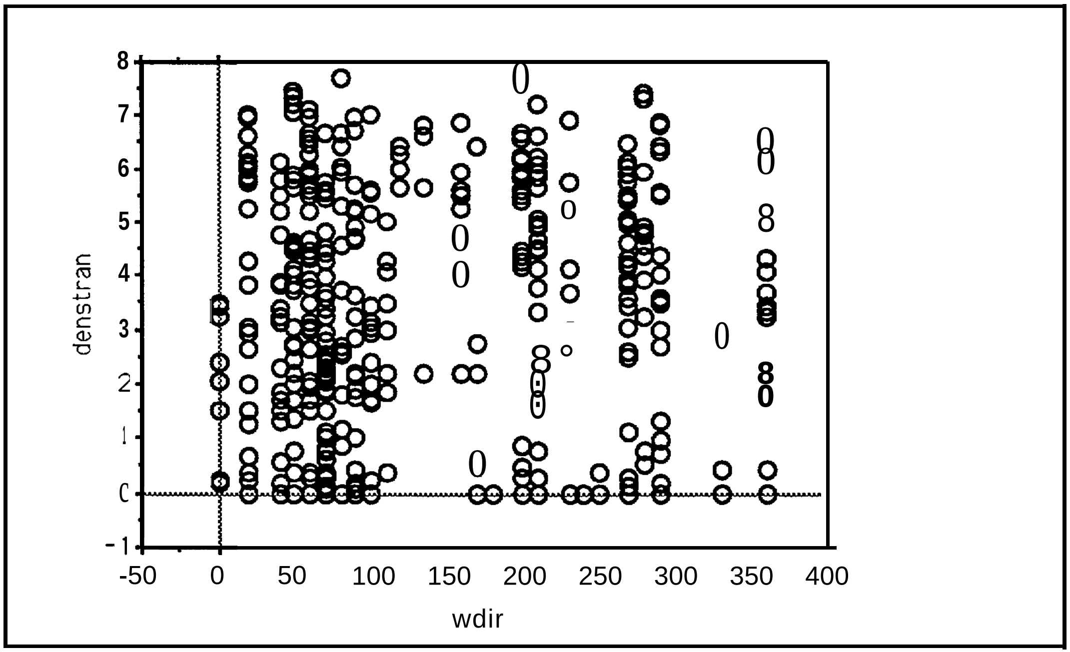
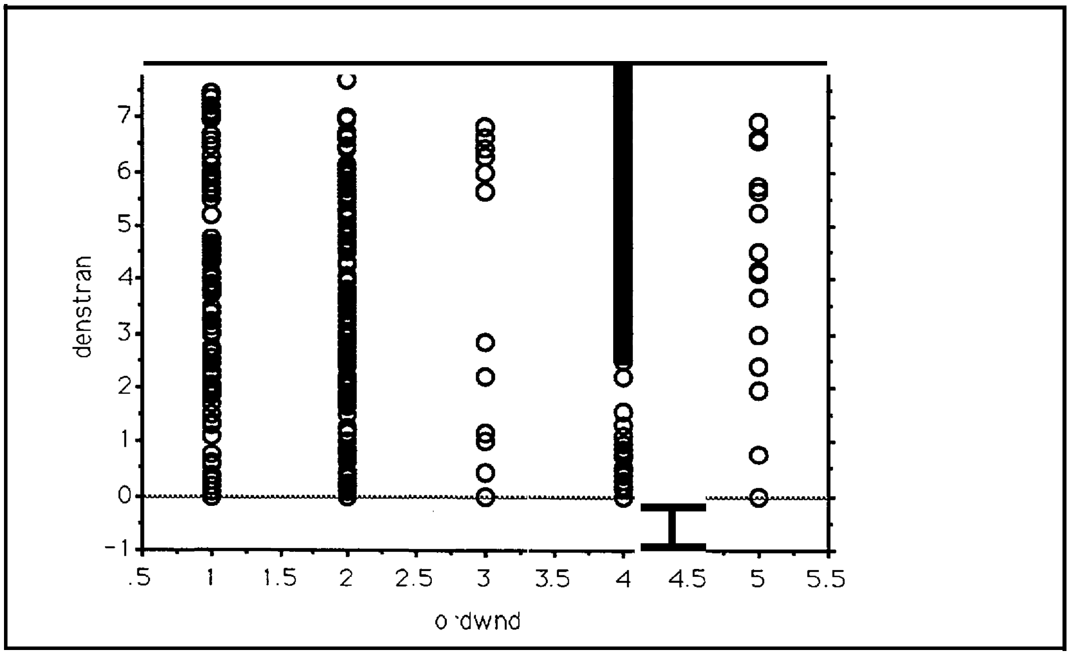
denstran
-5
0
5
10
15
20
25
30
35
40
45
50
wspd


denstran
wdir
8
7
6
5
4
3
2
1
0
-1
-50
0
50
100
150
200
250
300
350
400


denstran
-1
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1
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3
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3
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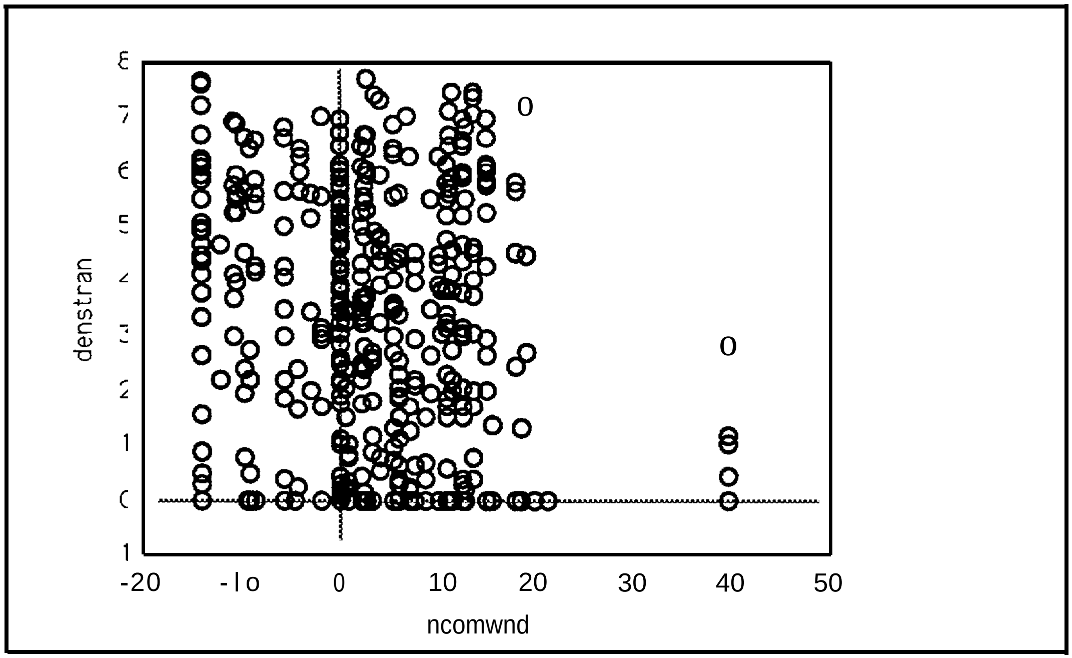
4
4.5
5
5.5
o·dwnd


denstran
ncomwnd
-20
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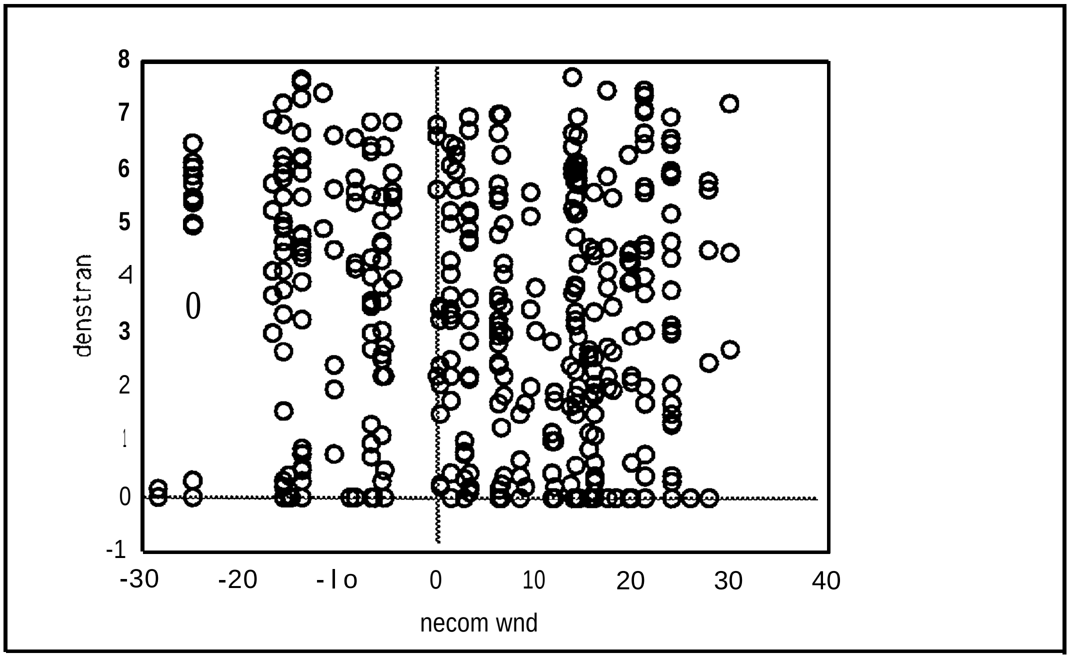
8
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denstran
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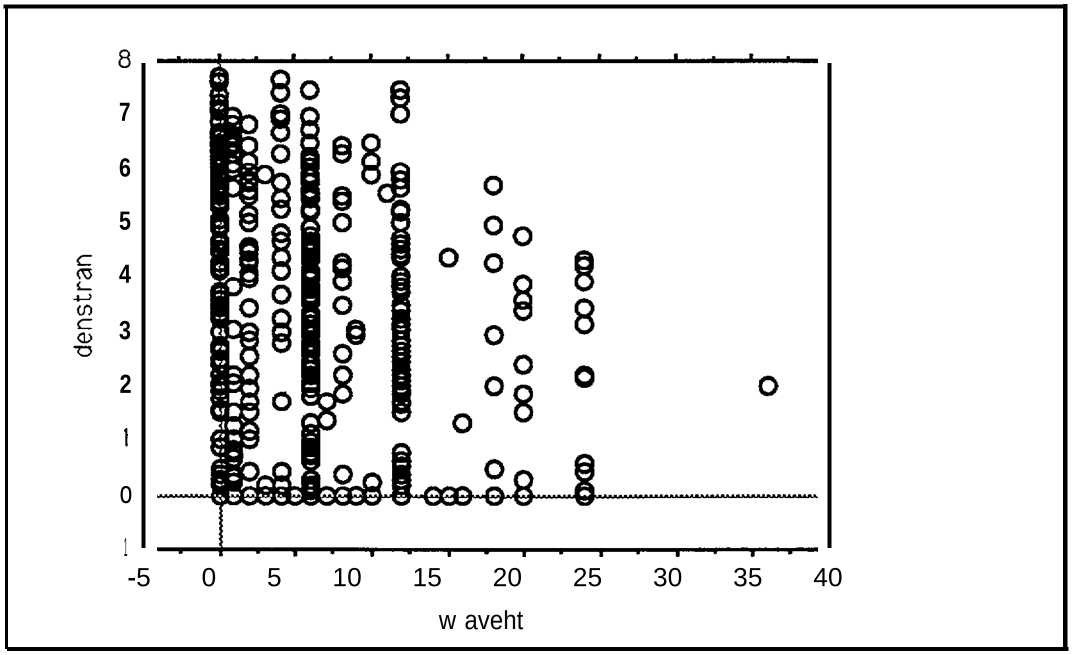
40
necom wnd


8
7
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denstran
-5
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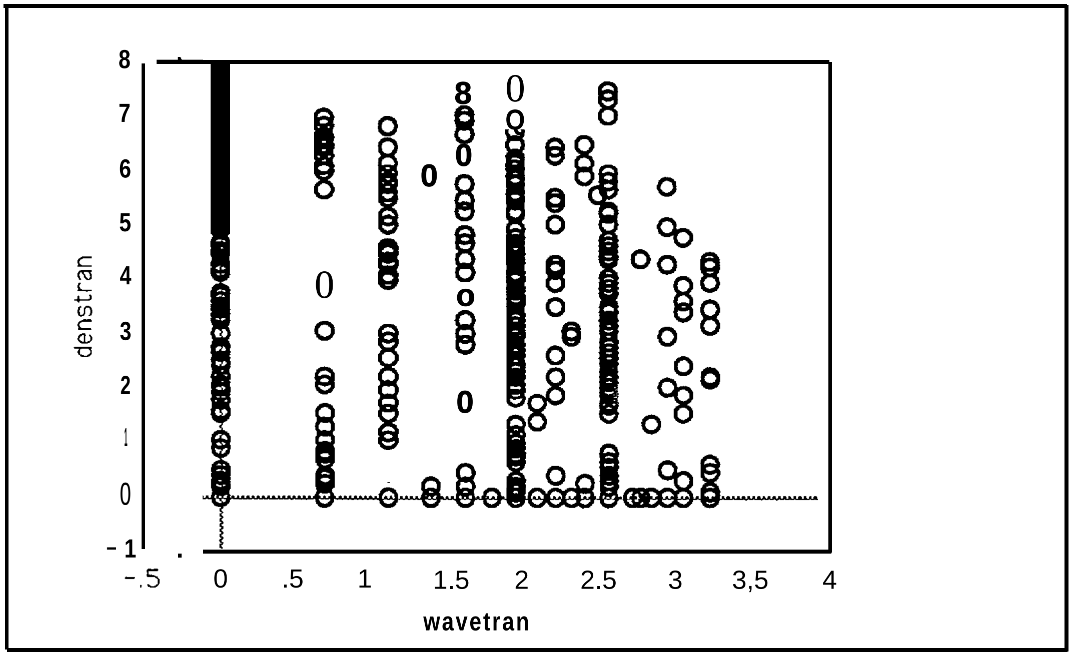
40
w aveht



denstran
8
7
6
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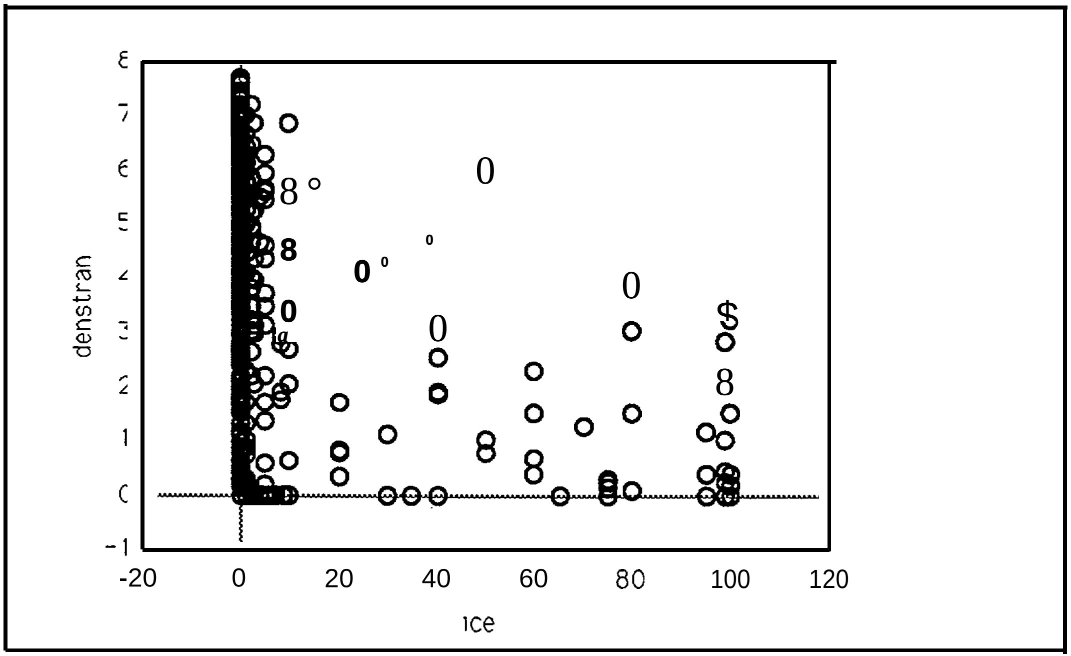
2.5
3
3,5
4
wavetran


denstran
ıce
-20
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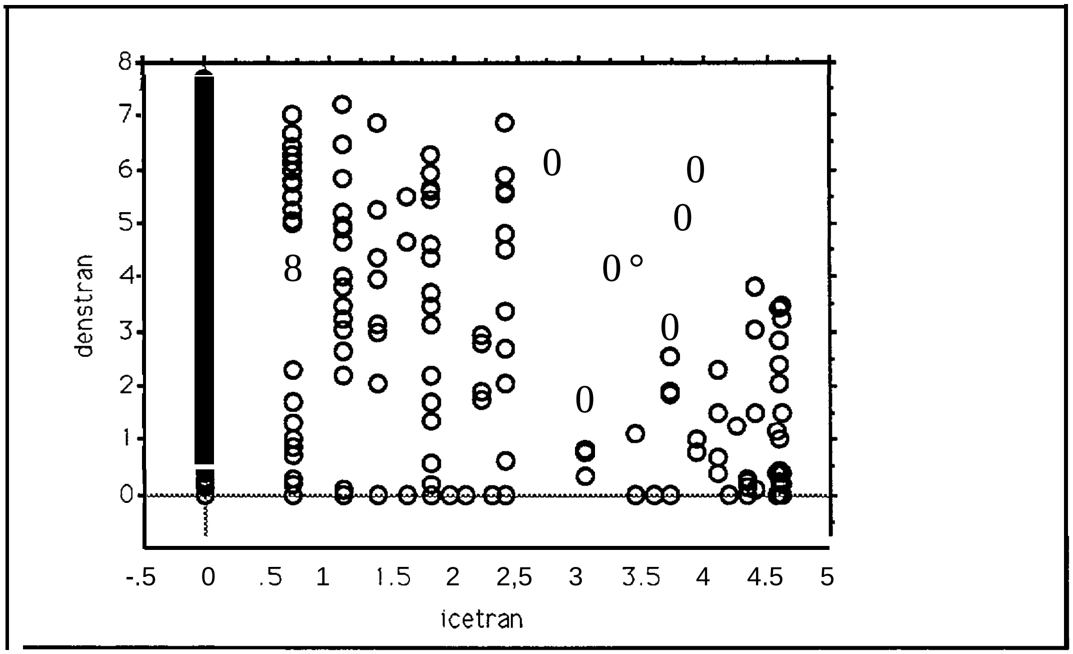
100
120


denstran
icetran
8
7
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4
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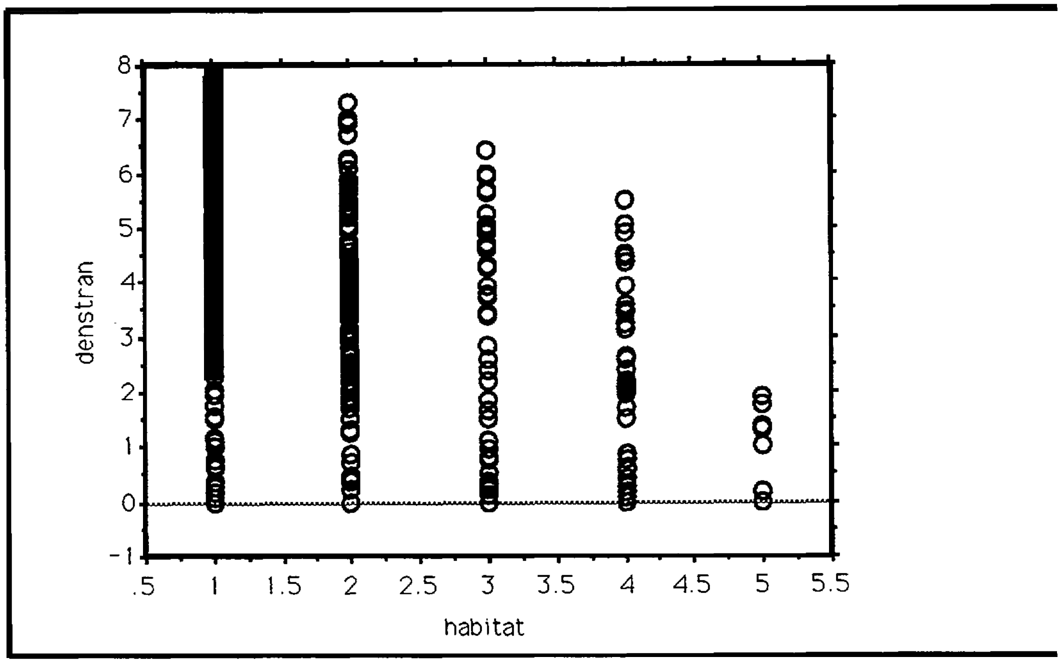
0
-.5
0
.5
1
1.5
2
2,5
3
3.5
4
4.5
5



denstran
habitat
8
7
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5
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-1
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1
1.5
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3
3.5
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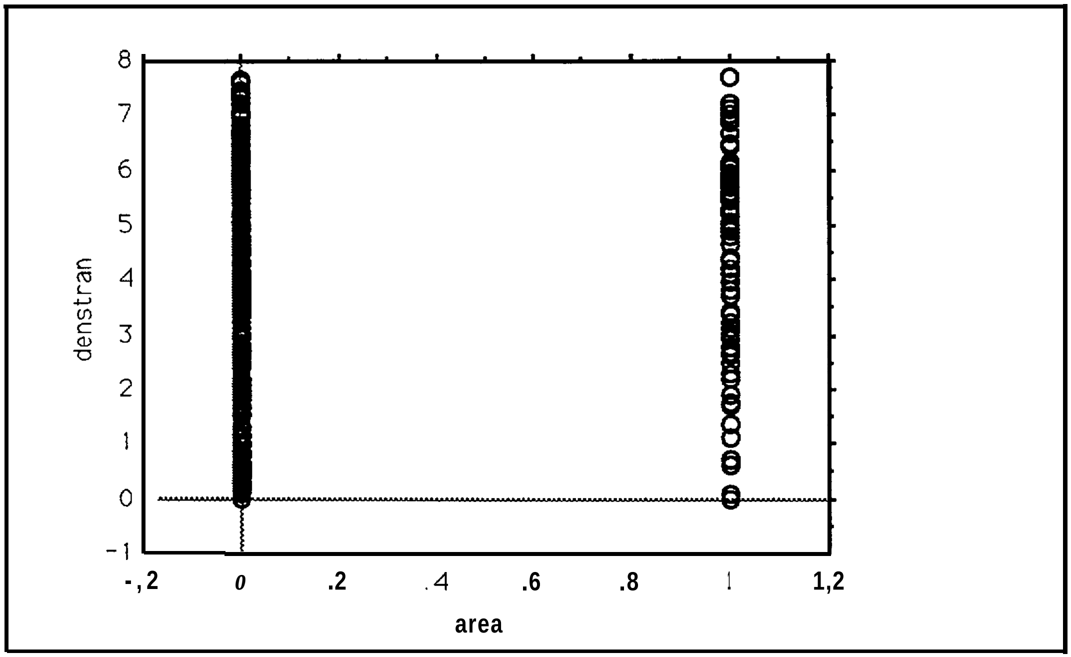
4.5
5
5.5


8
7
6
5
4
3
2
1
0
-1
denstran
-,2
0
.2
.4
.6
.8
1
1,2
area

LGL
Ecological Research Associates
1410 Cavitt Street Bryan, Texas 77801
(409) 775-2000